Proposed TMDL Report

Nutrient TMDL for West Clark Lake

(WBID 1971)

U.S. Environmental Protection Agency
Region 4

September 2005

Acknowledgments

EPA would like to acknowledge that the contents of this report and the total maximum daily load (TMDL) contained herein were developed by the Florida Department of Environmental Protection (FDEP). Many of the text and figures may not read as though EPA is the primary author for this reason, but EPA is officially proposing the TMDL for nutrient for West Clark Lake and soliciting comment. EPA is proposing this TMDL in order to meet consent decree requirements pursuant to the Consent Decree entered in the case of Florida Wildlife Federation, et al. v. Carol Browner, et al., Case No. 98-356-CIV-Stafford. EPA will accept comments on this proposed TMDL for 60 days in accordance with the public notice issued on September 30, 2005. Should EPA be unable to approve a TMDL established by FDEP for the 303(d) listed impairment addressed by this report, EPA will establish this TMDL in lieu of FDEP, after full review of public comment.

This study could not have been accomplished without significant contributions from staff in the Florida Department of Environmental Protection's Watershed Assessment Section

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Web sites

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION, BUREAU OF WATERSHED MANAGEMENT

TMDL Program

> http://www.dep.state.fl.us/water/tmdl/index.htm

Identification of Impaired Surface Waters Rule

> http://www.dep.state.fl.us/water/tmdl/docs/AmendedIWR.pdf

STORET Program

> http://www.dep.state.fl.us/water/storet/index.htm

2000 305(b) Report

> http://www.dep.state.fl.us/water/305b/index.htm

Criteria for Surface Water Quality Classifications

> http://www/dep.state.fl.us/legal/legaldocuments/rules/ruleslistnum.htm

Basin Status Report for the West Clark Lake Basin

> http://www.dep.state.fl.us/water/tmdl/stat_rep.htm

Assessment Report for the West Clark Lake Basin

> http://www.dep.state.fl.us/water/tmdl/stat_rep.htm

Allocation Technical Advisory Committee (ATAC) Report

> http://www.dep.state.fl.us/water/tmdl/docs/Allocation.pdf

U.S. ENVIRONMENTAL PROTECTION AGENCY, NATIONAL STORET PROGRAM

> http://www.epa.gov/storet/

Chapter 1: INTRODUCTION

1.1 Purpose of Report

This report presents the TMDL for nutrients for West Clark Lake (Lake) in the Sarasota Bay Basin. West Clark Lake is on the June 24, 2005 Secretarial Adopted Verified List of Impaired Waters for Group 3. In the list, West Clark Lake is referred to as Clark Lake in the Sarasota Bay Basin. As explained below, Clark Lake is really two separate lakes East Clark Lake and West Clark Lake. West Clark Lake has been classified as impaired by nutrients based on the Trophic State Index (TSI) being greater than 60 in 2003. For the only year with sufficient data to calculate a TSI (2003), the annual average chlorophyll a level was 43.66 μg/L, total phosphorus averaged 0.23 mg/L, and total nitrogen averaged 1.70 mg/L. The TSI based on averaging the four quarterly TSI values for 2003 was 69.35 (Table 2.10).

The Lake was verified as impaired by nutrients using the methodology in the Identification of Impaired Surface Waters Rule (IWR, Rule 62-303, Florida Administrative Code), and was included on the Verified List of impaired waters for the Sarasota Bay Basin that was adopted by Secretarial Order on June 24, 2005. This TMDL establishes the allowable loading to the Lake that would restore the waterbody so that it meets its applicable water quality criteria for nutrients.

1.2. Identification of Waterbody

West Clark Lake is located inside the City of Sarasota (City), Sarasota County, Florida, at Latitude 27^{o} 16” 28’ and Longitude 82^{0} 29” 53’. Looking at Figure 4.3, four small lakes can be identified. Lake West Clark Lake is the third lake in the series of four lakes inter-connected by culverts and a short canal. The southern most (upstream most) lake is Lake Mirror. This lake consists of 16.9 acres of surface area receiving runoff from 107 acres of a highly urbanized subbasin. During high water stages, Lake Mirror discharges to East Clark Lake through two 3.65’ diameter concrete culverts running under Clark Road. East Clark Lake has a surface area of about 11 acres and receives drainage from an area of about 440 acres and the overflow from Lake Mirror. The 440-acre contributing subbasin is primarily urban and residential. East Clark Lake discharges to West Clark Lake from the northern side along Beneva Road, through two concrete culverts of 3.65’ in diameter. It seems that the culverts are permanently submerged, and the rate of flow is regulated by a gradient of water level between the two lakes. West Clark Lake is the third lake along the direction of flow. This lake drains about 152 acres of predominantly residential land, and its surface area is 8.2 acres.

West Clark Lake discharges to the last waterbody, Red Bug Slough (a Sarasota County Aquatic Preserve), through a short canal with two triangular pipes at the outlet. The base of each pipe measures 6.7feet. Red Bug Slough is a small lake that transforms into two straight, narrow canals running parallel to one another, which eventually merge. Red Bug Slough connects to Philippe Creek a few miles to the north. Although the surface area of Red Bug Slough is relatively small, 9.3 acres, it drains nearly 633 acres of the surrounding land.

In this report we shall refer to the series of four lakes as the Lakes and West Clark Lake as the Lake. For assessment purposes, the State of Florida has been divided into waterbody assessment polygons termed Waterbody ID or WBID. The Lake is located inside WBID 1971 (see Figure 4.1).

1.3 Background Information

The TMDL Report for the Lake is part of the implementation of the Florida Department of Environmental Protection's (Department) watershed management approach for restoring and protecting water resources and addressing Total Maximum Daily Load (TMDL) Program requirements. The watershed approach, which is implemented using a cyclical management process that rotates through the state's fifty-two river basins over a five-year cycle, provides a framework for implementing the requirements of the 1972 federal Clean Water Act and the 1999 Florida Watershed Restoration Act (Chapter 99-223, Laws of Florida).

A TMDL represents the maximum amount of a given pollutant that a waterbody can assimilate and still meet the waterbody's designated uses. A waterbody that does not meet its designated uses is defined as impaired. TMDLs must be developed and implemented for each of the state's impaired waters, unless the impairment is documented to be a naturally occurring condition that cannot be abated by a TMDL or unless a management plan already in place is expected to correct the problem. The development and implementation of a Basin Management Action Plan, or BMAP, to reduce the amount of pollutants that caused the impairment will follow this TMDL Report. These activities will depend heavily on the active participation of the water management district, local governments, businesses, and other stakeholders. The Department will work with these organizations and individuals to undertake or continue reductions in the discharge of pollutants and achieve the established TMDLs for the impaired Lake.

Chapter 2: STATEMENT OF WATER QUALITY PROBLEM

2.1 Legislative and Rule Making History

According to Section 303(d) of the Federal Clean Water Act and the Florida Watershed Restoration Act (FWRA), Chapter 403, Florida Statues, the Florida Department of Environmental Protection is required to submit list of surface waters that do not meet applicable water quality standards, so-called impaired waters. The Department must also establish the Total Maximum Daily Load (TMDL) for those waters.

The FWRA (Section 403.067, F.S.) directed the Department to develop, and adopt by rule, a science-based methodology to identified impaired waters. This methodology is described as Chapter 62-303, Florida Administrative Code (Identification of Impaired Surface Waters Rule, or IWR), April 2001. Florida's 1998 303(d) list included 25 water bodies in the Sarasota Bay Basin, of which West Clark Lake is included as simply Clark Lake. The list of impaired waters in each basin, referred to as the Verified List, is amended annually to include basin updates.

2.2 Information on Verified Impairment

The Department used the IWR to assess water quality impairments in the West Clark Lake subbasin and verified that the Lake was impaired for nutrients. West Clark Lake was verified as impaired based on an elevated annual average Trophic State Index (TSI) value within the verification period (the Verified Period for the Group 3 basins is from January 1, 1997 to June 30, 2004). The TSI is calculated based on concentrations of TP, TN, and Chl a as follows:

$CHLA_{TSI} = 16.8 + 14.4 * LN(Chl\ a)$	Chl *a* in µg/L
$TN_{TSI} = 56 + 19.8 * LN(N)$	N in mg/L
$TN2_{TSI} = 10 * [5.96 + 2.15 * LN(N + 0.0001)]$	
$TP_{TSI} = 18.6 * LN(P * 1000) – 18.4$	P in mg/L
$TP2_{TSI} = 10 * [2.36 * LN(P * 1000) – 2.38]$	
If N/P > 30, *then* $NUTR_{TSI} = TP2_{TSI}$	
If N/P < 10, *then* $NUTR_{TSI} = TN2_{TSI}$	
if 10< N/P < 30, *then* $NUTR_{TSI} = (TP_{TSI} + TN_{TSI})/2$	
$TSI = (CHLA_{TSI} + NUTR_{TSI})/2$	(TSI has no units)

To calculate the TSI for a given year, there must be at least one sample in each season of the year. The analysis of the eutrophication-related problem in West Clark Lake used the only available data (from 2003) for which records of total phosphorus (TP), total nitrogen (TN), and chlorophyll (Chl a) were sufficient to calculate annual average conditions.

In 2003, the annual average concentrations of Chl a were 43.66 µg/L, TN was 1.70 mg/L, and TP was 0.23 mg/L, respectively. The measured color was 60 PCU or above throughout the year. Based on the above calculation for TSI, the TSI value for 2003 (only complete year of data) exceeded the IWR threshold level of 60. In fact, the 2003 TSI for West Clark Lake was 69.35 (average of the four quarterly TSI values). Exceeding a TSI of 60 in any one year of the verified period is sufficient to determine the Lake was impaired for nutrients.

Table 2.1. Measured Data and TSI for West Clark Lake (WBID 1971)

Month	TP	TN	Chla	TSI
Jan 2003				
Feb 2003				
Mar 2003	0.18	1.72	65	
Average	**0.18**	**1.72**	**65**	**74.1**
Apr 2003	0.23	2.20	4.3	57.2
May 2003	0.14	2.10	5.7	57
Jun 2003	0.11	1.90	22	65.1
Average	**0.16**	**2.07**	**10.67**	**62**
Jul 2003	0.26	1.80	55	73.4
Aug 2003	0.2	1.51	48	70.5
Sep 2003	0.26	1.60	55	72.1
Average	**0.24**	**1.64**	**52.67**	**72.1**
Oct 2003	0.4	1.02	88	70.7
Nov 2003				
Dec 2003	0.265	1.70	4.6	54.9
Average	**0.3325**	**1.36**	**46.3**	**69.2**
Annual Average	**0.23**	**1.70**	**43.66**	**69.35**

Chapter 3. DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND TARGETS

3.1 Classification of the Waterbody and Criteria Applicable to the TMDL

Florida's surface water is protected for five designated use classifications, as follows:

Class I	**Potable water supplies**
Class II	**Shellfish propagation or harvesting**
Class III	**Recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife**
Class IV	**Agricultural water supplies**
Class V	**Navigation, utility, and industrial use (there are no state waters currently in this class)**

West Clark Lake is classified as a Class III freshwaterbody, with a designated use of recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife. The Class III water quality criterion applicable to the observed impairment is the narrative nutrient criterion [Rule 62-302.530(48)(b), FAC].

3.2 Interpretation of the Narrative Nutrient Criterion

Florida's nutrient criterion is narrative only — nutrient concentrations of a body of water shall not be altered so as to cause an imbalance in natural populations of aquatic flora or fauna. Accordingly, a nutrient-related target was needed to represent levels at which an imbalance in flora or fauna is expected to occur. While the IWR provides a threshold for nutrient impairment for lakes based on annual average TSI levels, these thresholds are not standards and need not be used as the nutrient-related water quality target for TMDLs. In fact, in recognition that the IWR thresholds were developed using statewide average conditions, the IWR (Subsection 62-303.450, F.A.C.) specifically allows the use of alternative, site-specific thresholds that more accurately reflect conditions beyond which an imbalance in flora or fauna occurs in the waterbody.

The TSI originally developed by R. E. Carlson (1977) was calculated based on Secchi depth, chlorophyll concentration, and total phosphorus concentration and was used to describe a lake's trophic state. Carlson's TSI was developed based on the assumption that the lakes were all phosphorus limited. In Florida, because the local geology produced a phosphorus rich soil, nitrogen can be the sole or co-limiting factor for phytoplankton population in some lakes. In addition, because of the existence of dark-water lakes in the state, using Secchi depth as an index to represent lake trophic state can produce misleading results. Therefore, the TSI was revised to be based on Chl a, total nitrogen, and total phosphorus concentrations.

The Florida-specific TSI was determined based on the analysis of data from 313 Florida lakes. The index was adjusted so that a Chl a concentration of 20 ug/L was equal to a TSI value of 60. A TSI of 60 was then set as the threshold for nutrient impairment for most lakes (for those with a color higher than 40 platinum cobalt units) because, generally, the phytoplankton may switch to communities dominated by blue-green algae at Chl a levels above 20 ug/L. These blue-green algae are often an unfavorable food source to zooplankton and many other aquatic animals. Some blue-green algae may even produce toxins, which could be harmful to fish and other animals. In addition, excessive growth of phytoplankton and the subsequent death of these algae may consume large quantities of dissolved oxygen and result in anaerobic conditions in lakes, which makes conditions in the impacted lake unfavorable for fish and other wildlife. All of these processes may negatively impact the health and balance of native fauna and flora.

Because of the amazing diversity and productivity of Florida lakes, some lakes have a natural background TSI that is different from 60. In recognition of this natural variation, the IWR allows for the use of a lower TSI (40) in very clear lakes, a higher TSI if paleolimnological data indicate the lake was naturally above 60, and the development of site-specific thresholds that better represent the levels at which nutrient impairment occurs. For this study, the Florida Department of Environmental Protection (DEP) used modeling to estimate the background TSI by setting land uses to natural or forested land, and then compared the resulting TSI to the IWR thresholds. If the background TSI can be determined, then an increase of 5 TSI units above the background will be used as the water quality target for the TMDL. Otherwise, the IWR threshold TSI (based on color) will be established as the target for TMDL development.

Chapter 4: DETERMINATION OF CURRENT LOADING

4.1 Overview

The external load assessment was intended to determine the loading characteristics of the various sources of pollutants to the Lake. Assessing the external load entailed assessing land use patterns and rainfall to determine the volume, concentration, timing, location, and underlying nature of the nonpoint and atmospheric sources of nutrients to the Lake.

4.2 Types of Sources

An important part of the TMDL analysis is the identification of pollutant source categories, source subcategories, or individual sources of the pollutant of concern in the watershed and the amount of pollutant loading contributed by each of these sources. Sources are broadly classified as either "point sources" or "nonpoint sources." Historically, the term point sources has meant discharges to surface waters that typically have a continuous flow via a discernable, confined, and discrete conveyance, such as a pipe. Domestic and industrial wastewater treatment facilities (WWTFs) are examples of traditional point sources. In contrast, the term "nonpoint sources" was used to describe intermittent, rainfall driven, diffuse sources of pollution associated with everyday human activities, including runoff from urban land uses, agriculture, silviculture, and mining; discharges from failing septic systems; and atmospheric deposition.

However, the 1987 amendments to the Clean Water Act redefined certain nonpoint sources of pollution as point sources subject to regulation under the EPA's National Pollutant Discharge Elimination Program (NPDES). These nonpoint sources included certain urban stormwater discharges, including those from local government master drainage systems, construction sites over five acres, and a wide variety of industries (see Appendix A for background information on the federal and state stormwater programs).

To be consistent with Clean Water Act definitions, the term "point source" will be used to describe traditional point sources (such as domestic and industrial wastewater discharges) and stormwater systems requiring an NPDES stormwater permit when allocating pollutant load reductions required by a TMDL (see Section 6.1). However, the methodologies used to estimate nonpoint source loads do not distinguish between NPDES stormwater discharges and non-NPDES stormwater discharges, and as such, this source assessment section does not make any distinction between the two types of stormwater.

4.3 Potential Sources of Nutrients in the Lake Clark Basin

4.3.1 Point Sources

There are no permitted wastewater treatment facilities that discharge nutrient loads into the Lakes.

4.3.2 Municipal Separate Storm Sewer System Permittees

The West Clark Lake watershed falls under the Sarasota County MS4 permit (Number FLS000004). The City of Sarasota and Florida DOT are co-permitees with portions of their jurisdictions located in the watershed.

4.3.3 Land Uses and Nonpoint Sources

Unlike traditional point source effluent loads, nonpoint source loads enter at so many locations and exhibit such large temporal variation that a direct monitoring approach is often infeasible. For this project, all nonpoint sources were evaluated by use of a watershed and lake modeling approach. Table 4.1 shows the acreage of the various land use categories examined. Figure 4.3 shows the drainage basin of the Lake and the spatial distribution of the land uses shown in Table 4.1. The predominant land coverage is Medium Density Residential (56%) with Urban and Buildup second (12%) and High Density Residential following at 7 percent.

Table 4.1. Land Use/Cover Distribution in WBID 1971

Land Use Category	**Land Use Area (acres)**			
	Lake Mirror	**East Clark**	**West Clark**	**Red Bug S.**
Urban and built-up	11.0	136.9	4.0	15.2
Low Density Residential	11.7	42.8	0.0	5.9
Medium Density Residential	32.0	181.8	92.0	469.8
High Density residential	43.2	0.1	23.8	31.2
Agriculture	0.0	21.4	0.0	22.0
Rangeland	0.0	0.0	0.0	0.0
Forest	0.0	28.6	7.9	32.7
Water	25.2	22.0	12.3	16.1
Wetlands	0.0	35.6	1.1	7.4
Barren Land	0.0	0.0	0.0	33.1
Transportation, Communications, and Utilities	1.3	1.2	9.9	0.0
Total =	**124.4**	**470.4**	**150.9**	**633.4**

4.4. Historical Development of the Area

No one whom we contacted regarding West Clark Lake knew the history of the site. However, the map of Lake Clark from 1847 (with present streets overlaid), and shown in Figure 4.1, gives some insight into the pre-development look of the Lakes. At that time one lake or wetland existed that had no evident connection to another waterbody or outlet. By 1948, the site was dredged, with the shoreline redesigned to extend further north and south of the original lake. While the city was developing, Lake Clark was reconstructed at least one more time, apparently to provide a scenic background for surrounding condominiums and houses (see Figure 4.2).

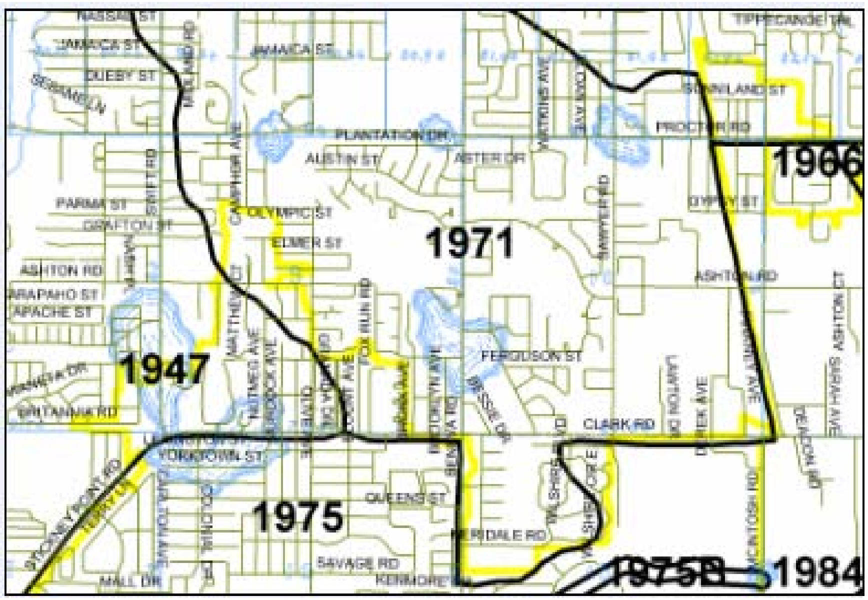

Figure 4.1. Early Map of Lakes Area

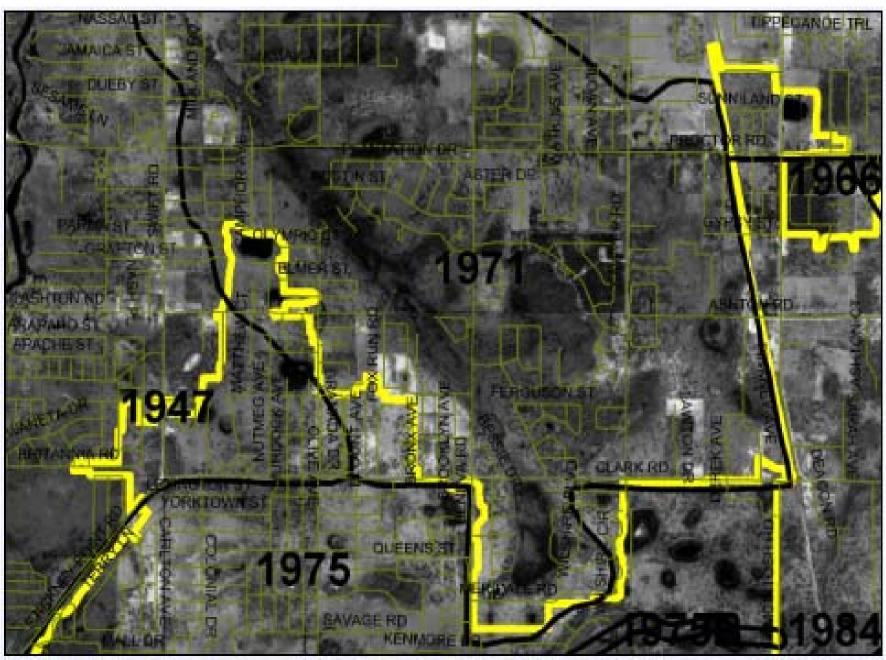

Figure 4.2. Aerial Photograph of Lake Clark Site in 1948

4.5 Modeling of Nonpoint Sources

Although only West Clark Lake has been classified as impaired, the water quantity analysis needed to be done for all four lakes altogether. Lake Mirror is the upstream most lake and feeds the whole system with water. Its stages indirectly determine the flow regime of waterbodies located downstream.

East Clark Lake links Lake Mirror and West Clark Lake. Discharges from this lake provide significant inflow to West Clark Lake, as is evidenced later in this report.

From the opposite side of West Clark Lake, Red Bug Slough also needed to be included. However, the reason for this was more technical than hydrologic. Slightly north (i.e. downstream) of Red Bug Slough, at Proctor Street, is the only flow gauge station that measures discharges from Lakes' basin. The outflow volume is one of several components of the water budget of any water system. Because no flows *between* the lakes are known (measured), those missing flows needed to be simulated by a computer model, and the only data suitable for verification of our estimates came from the flow gauge station downstream of Red Bug Slough. Assuming that the total flows simulated by the model correctly recreate the real flows at the mouth of the basin, then it is believed that the simulated flows into and out of each lake in the basin are realistic estimates of the real flows between the four lakes.

Water Budget for a Lake

For a time span $\Delta T = t_1 - t_0$ the following water continuity equation holds

$$V_1 = V_0 + SR + In + DR + GW - Ev - Out \qquad (1)$$

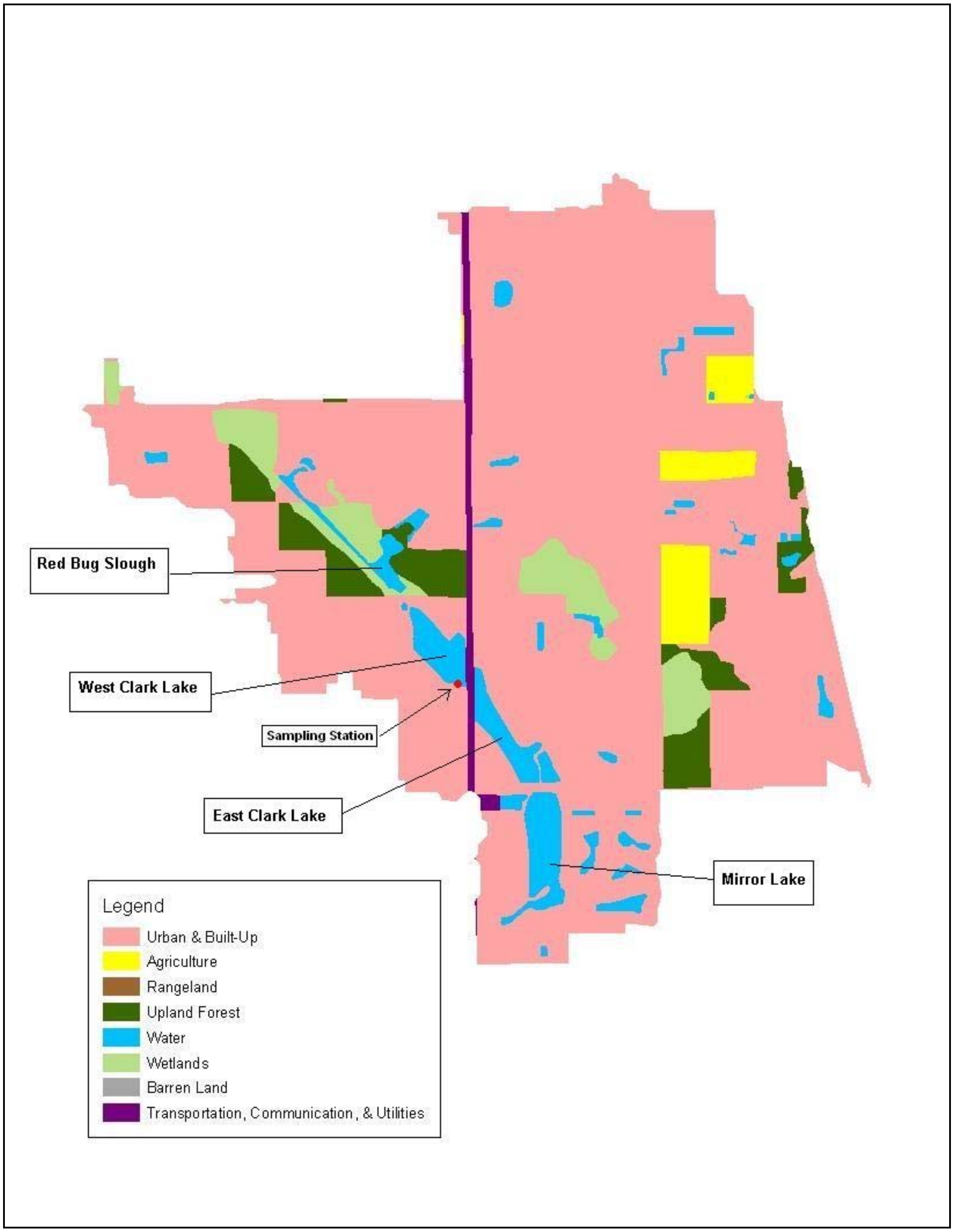

Figure 4.3. Map of Lake Clark basin and land use categories. Divides of particular subbasins may be found in Appendix D

where

V_i	=	volume of water stored in a lake at moment t_i (i = 0 or 1),
SR	=	surface runoff, i.e., portion of rainfall directly discharging from a basin,
In	=	concentrated inflow such as tributary or upstream inflow,
DR	=	direct rainfall, i.e., rainfall that directly falls on lake's surface,
GW	=	ground water supporting the lake,
Ev	=	lake's evaporation,
Out	=	discharge from the lake.

The component most difficult to control and assess is ground water. Quite likely, the Lakes are connected to a shallow ground water aquifer for which the water stage is not known. Additionally, the permeability of the ground water – lake interface was never examined. Therefore, ground water is considered as an unknown component of the water continuity equation. For the equation to be solvable, it may have only one unknown. Therefore the remaining components must be somehow assessed. During development of the TMDL for nutrients in West Clark Lake, substantial effort has been made to derive valid estimates of the remaining components of Equation 1.

Discharges from the Lakes and Rainfall Data

Since water quality data were collected only during 2003, that year became both the optimization period as well as the verification period in the analysis. Environmental Services of Sarasota County provided the daily flow data collected by the gage at Proctor Street. For the purposes of this study, the flow gage site is considered as the mouth of basin. The station apparently came into operation near end of June 2003, so flows during the first half of 2003 were not collected. Then, being in operation for four months, the gage malfunctioned near the end of October 2003. Comparison of flows and rainfall records from seven surrounding stations indicated that the gage recorded unreliable flows until the end of April 2004. Those unreliable data were discounted.

Due to paucity of data, Environmental Services provided additional records of flow extended to October 13, 2004. Environmental Services also provided rainfall records from the surrounding stations. Wherever possible, records from the seven stations that virtually surround the Lakes basin were used in this analysis. However, there were months for which reliable rainfall records were available from only two stations. Detailed analysis of rainfall records and the coincidental flows disclosed the very local nature of many storm events. It wasn't an isolated case to observe rain of an inch or more at one station and no rain at a station just a few miles away. A storm event that occurred on May 17, 2004 may serve as an example: on that day the 7 stations, recorded 0.00, 1.17, 1.08, 0.65, 0.00, 0.91, and 0.90 inches of rain. Additionally, for several periods, increased flows at the gage site could not be related to any rain in the area.

Figure 4.4. Rainfall stations from which data were used in this analysis: PH-5, PH-8, PH-9, PH-10, HUD-2, MAT-1, and EL-1. The Lake Clark basin is located directly below station PH-9 where blue and green polygons are readily visible

The location of the 7 rainfall stations included in the analysis for the Lakes basin is shown in Figure 4.4. The rainfall records were weighted as reversely proportional to the distance from the center of the basin. That means that weights assigned to stations closer to the basin were greater than the weights of the stations being further away. The greatest weight was assigned to station PH-9 located at the mouth of Lakes basin off Proctor Road adjacent to the flow gage (see Figure 4.4).

Separation of Surface Runoff from Total Flow

Records of flows consist of *total* flows of which only a portion is generated at the surface of a basin, and for this is named *surface runoff*, and the remaining water, so-called *baseflow*, which consists of combined interflow and ground water.

Separation of surface runoff from baseflow is one of the more primitive procedures in hydrology. This is because quantifying the role of soil water is a difficult task and still relatively little is known about the contribution of vadose water and ground water to stormwater in a basin. The hydrologic textbooks provide only simple methods of baseflow separation techniques. One of the newer methods is termed 'Digital Filter.' This method separates low frequency (baseflow) from high frequency (direct runoff) for any series of stream flow. For this analysis, the two-parameter Digital Filter method was selected [1]. At each time step

$$B_K = [(1 - BFImax)\, a\, B_{K-1} + (1 - a)\, BFImax\, Q_K] / (1 - a\, BFImax) \qquad (2)$$

with the restriction that

$$B_K \leq Q_K \qquad (3)$$

In those equations, B_k designates baseflow on day k, and Q_k the total flow on day k. Equation (2) has two parameters. One of them, *BFImax*, is the maximum value of the baseflow index that can be modeled by the algorithm. This parameter is a nonmeasurable quantity. In order to minimize the subjective influence that a user exerts on the results by the choice of *BFImax*, one has to find typical *BFImax* values for classes of catchments that can be distinguished by their hydrological and hydrogeological characteristics. In his website, Dr. Eckhardt [1] wrote that based on a preliminary analysis of the literature, he recommended using the value 0.80 for perennial streams with a porous aquifer, a value of 0.50 for ephemeral streams with a porous aquifer, and a value of 0.25 for perennial streams with a hard rock aquifer.

The other parameter of Equation (2), *a*, corresponds to the recession constant in the equation

$$Q_K = a\, Q_{K-1} \qquad (4)$$

and describes the baseflow slope on the falling limb during periods of exclusive ground water discharge [9]. Separation of baseflow in this system of lakes has been performed with the recession constant equal to 0.98 and a baseflow index 0.80. Figure 4.5 shows the estimated baseflow (brown area) overlaying the total flow in a 52-day period in 2004. The difference between those two (blue area) is surface runoff, generated by rain on the basin's surface.

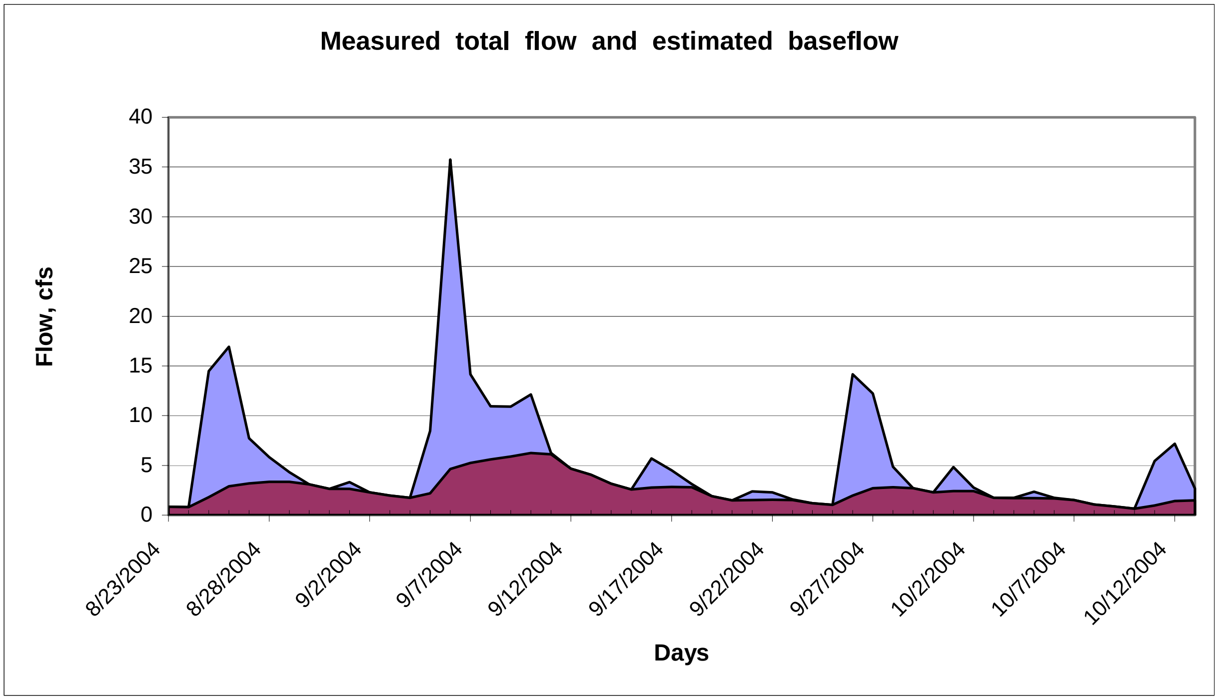

Figure 4.5. A fragment of total hydrograph observed in Red Bug Slough in 2004 with overlaid baseflow component estimated by Digital Filter. The difference between those two (visible blue area) is surface runoff

Estimate of Missing Surface Runoff in the Lakes by a Computer Model

Only four months of reliable flow data have been collected at the outlet of the Lakes basin for 2003. The missing flows could be predicted if a mathematical representation of the operation of the basin were developed, and the required input data were available. Fortunately, only the rainfall records and physical parameters of a basin are needed to run a simple simulation model.

There are a variety of tools to model the rainfall – runoff relationship that differ primarily in the extent of the hydrologic processes represented. A complex hydrologic model such as HSPF calculates surface runoff and baseflow, while a simple and mechanistic model only calculates surface runoff. In this analysis, the United States Department of Agriculture (USDA) Soil Conservation Service Curve Number (SCS CN) method was applied as the primary model. This method calculates surface runoff based on runoff coefficients (Curve Numbers) that correspond to different land uses and antecedent precipitation. Therefore, we believe that this method is superior to those methods that use one or two runoff coefficients for the whole basin.

In the early 1940's investigators from the USDA related storm runoff to rainfalls and showed that the ratio of cumulative discharge to cumulative storm rainfall takes a characteristic form depicted in Figure 4.6. These results were summarized in the following equation

$$\frac{Q}{P - I_a} = \frac{P - I_a}{S + P - I_a} \tag{5}$$

in which

Q = runoff volume in cubic feet from P inches of rainfall,

S = maximum volume of basin's retention, depends on soil type and state of the soil moisture,

I_a = initial "losses" of precipitation.

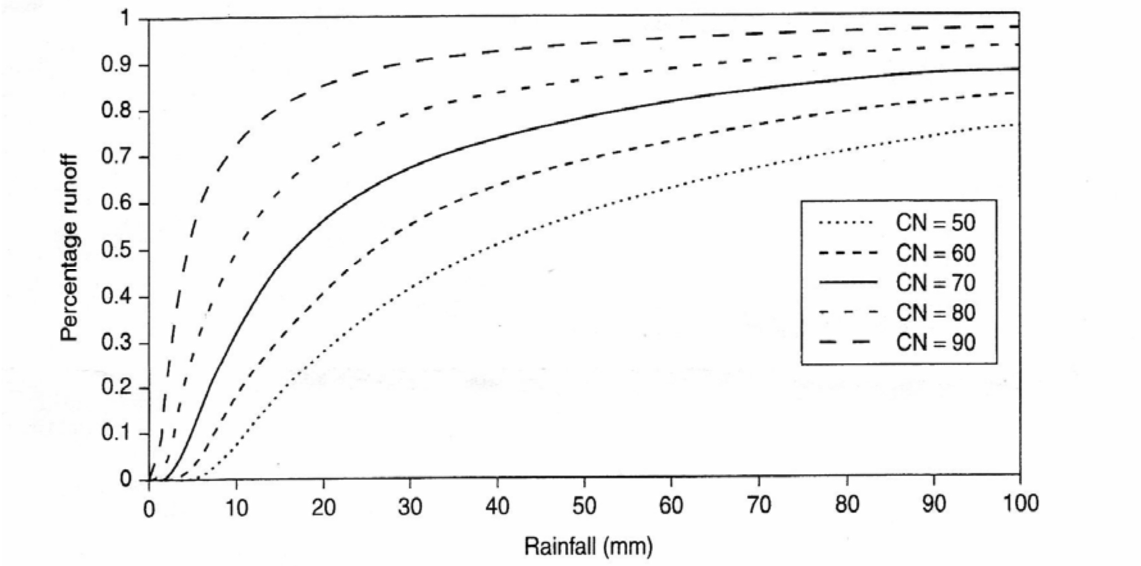

Figure 4.6. Variation of runoff with curve number (CN) which is an indicator of retention ability of a watershed

The initial losses are the fraction of the basin's retention, that may be written as $I_a = a\,S$, where the coefficient *a* may vary from basin to basin.

The strength of the SCS CN method is that it allows for the dependence of a basin's retention on the level of moisture in the soil, represented by the Curve Number (CN):

$$S = C\left(\frac{100}{CN} - 1\right) \qquad (6)$$

The parameter *C* takes value of 10 inches, i.e. 254 mm. Consequently, for CN $\geq$ 50, retention volume varies between 0 and 254 mm.

For areas of complex land use, it has been normally suggested that a linear combination of the component curve numbers, weighted by the area to which they apply, should be used to determine an effective curve number for the area (e.g. [7]). However, because of the nonlinearity of the runoff prediction equation, this will not give the same results as applying the equation to each individual area and weighting the resulting runoff by the component fractional areas. Grove at al. [6] showed that using a distributed runoff curve number calculation would increase the volume of predicted runoff, by as much as 100 percent in their examples, relative to using the composite method. In this analysis, Grove's suggestion, i.e. the distributed runoff curve number approach was applied.

The original SCS National Engineering Handbook [2] provides a table containing different values for Curve Number for specific land uses and for three situations: dry condition, average (or typical) condition, and wet condition. The suggested switch from one soil condition to another is as Table 4.2 shows:

Table 4.2. Range of Application of AMCs as Suggested by USDA

AMC	Total 5 - day antecedent rainfall (cm)	
	Dormant season	Growing season
I	less than 1.3	less than 3.6
II	1.3 to 2.8	3.6 to 5.3
III	more than 2.8	more than 5.3

After preliminary experimentation, it was found that a smooth transition from one condition to another produces predicted runoff volumes that fit the measured surface runoff. To make a smooth transition it has been assumed that for antecedent precipitation index (API) equal to zero, the CN corresponding to dry condition holds, and afterwards CN linearly increases to the value corresponding to the wet condition until API reaches some level γ. Parameter γ for a given basin was assessed in the process of optimization. In the middle of the range (0, γ), CN takes the value that corresponds to the typical condition. In the model, for each land use,

$$CN = IF(API<\gamma/2,\ AMCI+(AMCII-AMCI)*API\ /(\gamma/2),\ IF(API<\gamma,\ AMCII+(AMCIII-\ AMCII)*(API-\gamma/2)/(\gamma/2),\ AMCIII)) \quad (7)$$

Here, *AMCI*, *AMCII*, and *AMCIII* correspond to the Curve Number for dry condition, typical condition, and wet condition, correspondingly.

Using 280 daily flows measured near the outlet from the Lakes basin during 2003 and 2004, the three parameters of the SCS CN model were optimized: parameter *a* in equation $I_a = a\ S$, parameter γ, and parameter *k* in expression for *API*

$$API = k\ P_{-1} + k^2\ P_{-2} + k^3\ P_{-3} + k^4\ P_{-4} + k^5\ P_{-5} \quad (8)$$

Here P_{-i} stands for rainfall that occurred *i* days earlier. The optimization process consisted of a minimization of the sum of squares of the differences between the simulated and observed daily volumes of surface runoff. After optimization, the total simulated volume of surface runoff during those 280 days was 50,832,222 cubic feet and the total volume of surface runoff measured in the stream was 49,799,160 cubic feet. This indicates a 2% difference in the estimate of total runoff.

As described previously, the Lakes basin, shown on Figure 4.3, has been divided into four subbasins, each contributing surface runoff to only one lake. For all subbasins, the same values of a, γ, and k were applied, however, the acreage of land uses differed from one basin to another. The runoff volumes provided in the previous paragraph are the cumulative runoffs from all four subbasins. The land use categories identified in the Lakes basin and their acreage are listed in Table 4.1. Table 4.3 summarizes the monthly volumes of surface runoff produced by the rainfall in each of the four lake subbasins in 2003. These runoffs were estimated as previously described by the SCS CN method.

Shaping Flows into Hydrograph

The SCS CN method predicts the volume of runoff resulting from a given storm event. However, the SCS CN method can not depict how the runoff volume is distributed in time. Even from such an average-sized basin as the Lakes basin, the runoff can be prolonged for a day or two. The temporal distribution of the runoff volumes predicted by the SCS CN method was needed for two reasons: Comparison of the simulated surface runoff to the measured runoff would be an extra check that the model itself is well calibrated. This extra check was worth completing, especially in the situation where ¾ of measured discharges from the Lakes basin was missing. Additionally, a monthly water balance analysis for the individual lakes requires good estimates of monthly inflows and outflows from the lakes.

Table 4.3. Surface Runoff Reaching Lakes Estimated by a Mathematical Model

Month	Surface runoff entering the lakes in 2003			
	Lake Mirror	East Clark	West Clark	Red Bug Slough
	Cf	cf	Cf	cf
January	161,502	421,216	131,636	393,681
February	143,266	226,693	83,056	154,252
March	311,241	675,645	222,355	576,801
April	395,811	996,994	318,174	946,884
May	647,186	1,733,778	548,784	1,725,268
June	5,647,031	19,043,900	5,997,865	22,827,814
July	624,186	1,370,802	444,565	1,141,751
August	1,447,000	3,708,234	1,169,843	3,488,425
September	1,377,110	4,004,974	1,259,604	4,245,860
October	182,151	319,742	111,517	227,922
November	219,226	474,603	155,797	400,163
December	658,873	1,892,863	591,245	1,952,048

Any basin or waterbody such as a lake or a reach of a stream has its own storage. By observing the output from such a hydrologic object and comparing it to the input that caused that output, one can see that the storage effect manifests in at least two features: attenuation and delay in time. The SCS CN method is unable to simulate either of these effects, and therefore the runoff volumes were routed through each of the *conceptual* storage elements. For simplicity of calculations, a storage element was assigned to each pair of lakes and it's discharging subbasin. The cascade of storage elements was schematically shown in Figure 4.7.

For any given storage element, a continuity of volume of water equation, written here in the form of finite differences, holds

$$\boxed{0.5\left(I_0 + I_1\right) - 0.5\left(Q_0 + Q_1\right) = \frac{S_1 - S_0}{\Delta t}} \qquad (9)$$

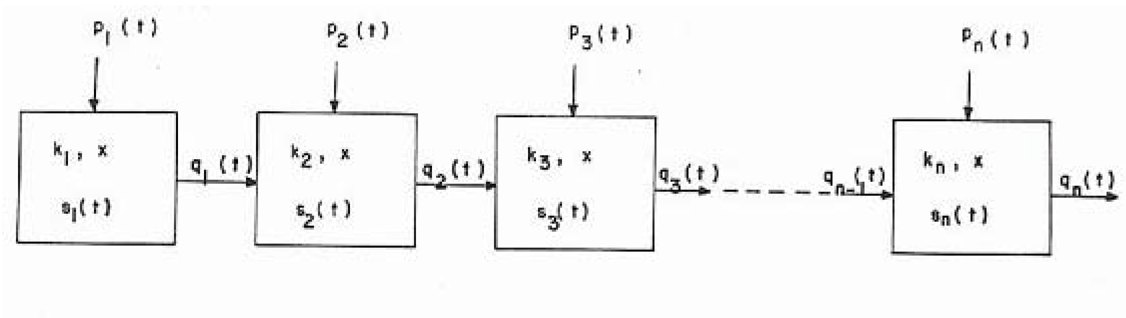

Figure 4.7. A nonlinear hydrologic cascade with distributed input reprinted from [4]. Here p_i denotes surface runoff from a contributing subbasin, and q_i is outflow from storage element i that feeds next element i+1

This equation states that an average input *I* during the time increment Δt, less an average output *Q* in the same time span causes an increase in the volume of stored water, *S*. Subscripts *0* and *1* refer to two consecutive moments Δt time interval apart. Knowing the initial condition of the system, i.e. input I_0, output Q_o, and storage S_o, plus knowing the new input I_1, Equation (9) can be solved for the unknown output Q_1. However, Equation (9) has another unknown, new storage S_1, and therefore a second equation needs to be coupled with Equation (9). This second equation links stored water, *S* to discharge *Q*,

$$S = k\,Q^m \tag{10}$$

so that stored volume, *S*, may be eliminated from Equation (9). The resulting equation is a nonlinear ordinary differential equation with no known analytical solution. However, it can be solved by means of numerical methods.

To start the iterative process, the initial value of Q_{i+1} is set equal to $(I_i + I_{i+1})/2$. Application of the Newton – Raphson method gives a better approximation of discharge, thus [3]

$$Q'_{i+1} = Q_{i+1} - \frac{\Delta t\left(Q_{i+1} + Q_i - I_{i+1} - I_i\right) + 2k\left(Q^m_{i+1} - Q^m_i\right)}{\Delta t + 2k\,Q^m_{i+1}} \qquad (11)$$

If $\left|Q'_{i+1} - Q_{i+1}\right|$ exceeds some acceptable error, Q_{i+1} is given the value Q'_{i+1} and Equation (11) is repeated. In the calculations, two iterations on each time step were performed. After some experimentation, it was found that a one-hour time step was needed to preserve acceptable accuracy. This means that daily flow was calculated in 24 one-hour steps, and the average of the outcomes became an average surface runoff for that day.

The need to use a time step interval of less than a day created some additional problems. The surface runoff from each of the four subbasins, estimated by the SCS CN method, is a daily total volume. However, to perform flood routing using Equation (11), a hourly distribution of that runoff was needed. This could be accomplished in several ways. Some hydrologists assume a random distribution and use a random number generator. Others assume a uniform distribution. In our calculations, a parabolic distribution, such as shown in Figure 4.8, was selected. This distribution, in our opinion, more closely resembles the actual surface runoff that occurred.

The parameters used in the cascade of nonlinear storage elements model were four coefficients *k*, one for each lake and its subbasin, and the parameter *m*. The optimal values of those parameters were found during the process of minimizing the total sum of the absolute differences between the measured and simulated daily average surface runoffs during the 280 days of 2003 and 2004 for which measured data exist.

Figure 4.9 shows 88 out of 280 continuous days of the hydrograph measured at the creek coming out of Red Bug Slough and simulated by a spreadsheet model to illustrate the accuracy of simulated peaks and time of occurrence. Routing of the total discharges through a cascade of linear or nonlinear reservoirs preserves the total volume of water since the water mass continuity equation, Equation (9), is part of the model. Additionally, routing provides the shape of a typical hydrograph, and controls for time lag.

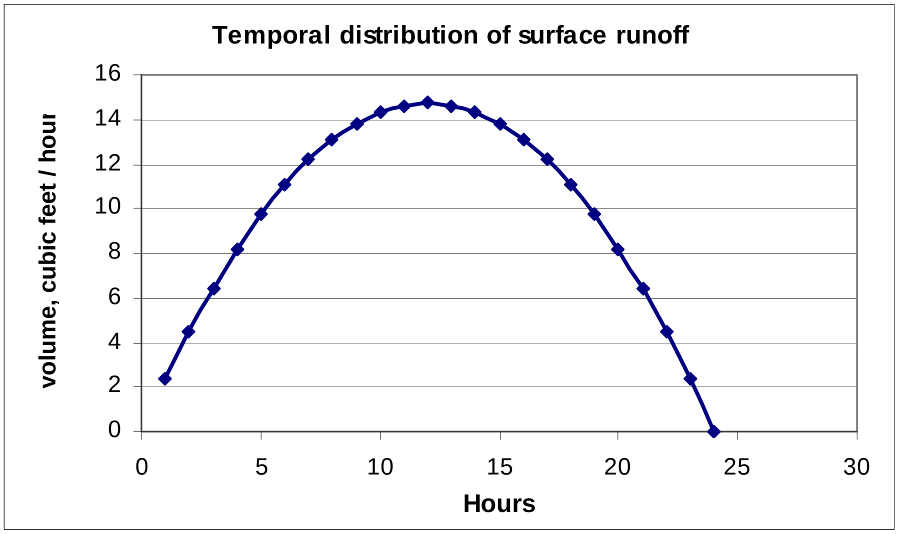

Figure 4.8. Assumed distribution of 235.80 cubic feet of surface runoff that occurred in Lake Mirror subbasin on 1/29/2003

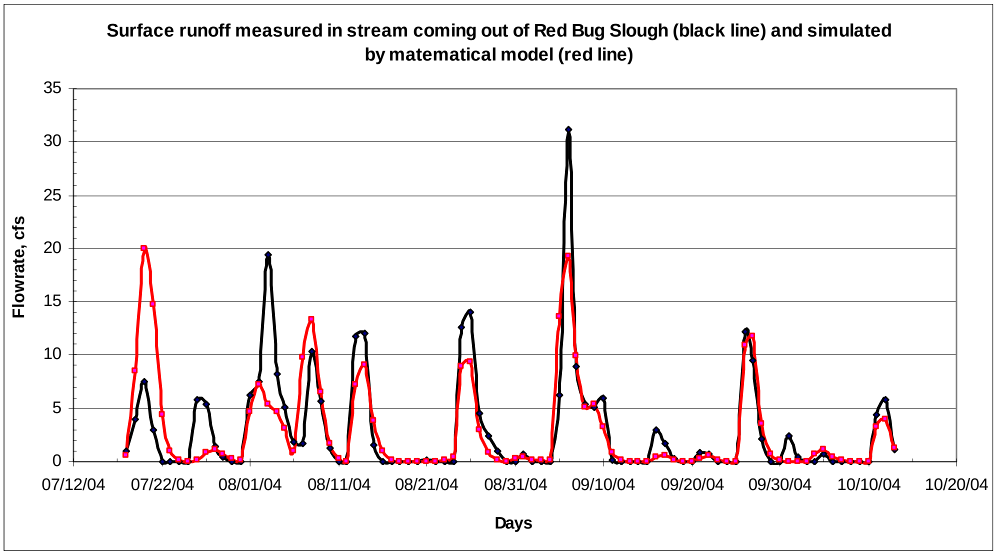

Figure 4.9. Surface runoff component measured in stream coming out of Red Bug Slough and modeled by combination of SCS CN and series of storage element models

Correctly selected values for parameter k_i should assure the model predicted surface runoff coincides with the observed runoff in a stream. Overestimation of k_i would make predicted runoff lag behind the observed runoff and the peaks would be excessively dampened.

Complementing Surface Runoff by a Baseflow

The SCS CN method can predict surface runoff from rainfall. However, the water continuity equation, Equation (1), applies total runoff. This total runoff aggregates surface runoff and subsurface runoff (baseflow) which reflects interflow and the contribution of ground water.

There was a need for an assessment of a baseflow that corresponds to known surface runoff. Here, a simple but unique approach has been elaborated, partly due to the lack of a single accepted method for the assessment of baseflow. Rewriting Equation (2) as

$$B_K = [(1 - BFImax)\ a\ B_{K-1} + (1 - a)\ BFImax\ (SR_K + B_k)] / (1 - a\ BFImax) \qquad (12)$$

since total flow, Q_k, is the sum of surface runoff, SR_k, and baseflow, B_k. Arranging Equation (12) so that the only unknown, B_k, stands on the left side of the equation, obtains

$$B_k = a\,B_{k-1} + \frac{(1 - a)BF\,\mathrm{Im}\,ax}{1 - BF\,\mathrm{Im}\,ax}\ SR_k \qquad (13)$$

Equation (2) estimates baseflow from the known total flow and the baseflow one day earlier. Equation (13) makes the same estimate from surface runoff and yesterday's baseflow. First, a series of estimated baseflows were calculated for consecutive days initiated from a day for which measured total flow and assessed surface runoff were available. Then, the final baseflow was calculated as the difference between those two

$$B_o = Q_o - SR_o \qquad (14)$$

In the prediction of baseflow, Equation (13) was partly used in the form shown above and partly rearranged for B_{k-1} as an unknown, depending on the arrangement of measured flows (in other words, sometimes baseflow was calculated backwards in time). Care had to be taken while applying Equation (13), as the condition provided as Equation (3) could not be implemented. Therefore, this process was somewhat subjective. Finally, the predicted baseflow was added to the predicted surface runoff to generate the total average daily flow in all the days in 2003 during which the total flow was not monitored. Use of Equation (13) provided consistency in the way baseflow was estimated for those days when total flow was measured and those days for which total flow was not measured. To provide better insight into the reconstructed total flows in 2003, the correspondence of the monthly flows to monthly rainfalls is provided in Figure 4.10.

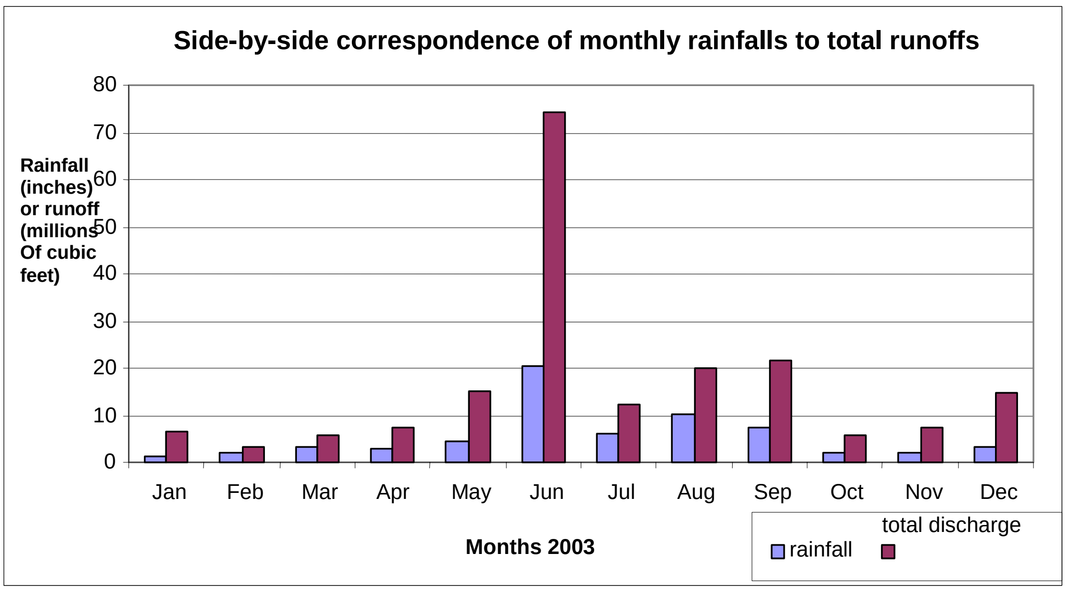

Figure 4.10. Total flows aggregated in monthly sums and the corresponding monthly rainfalls. In June 2003, 20.51" of rain was recorded in the Lakes basin that made June an unusually wet month

Estimates of Total Monthly Outflows from the Lakes

As a result of the simulations performed by the models (SCS CN and hydrologic cascade of nonlinear reservoirs) the outflows from each of the four lakes, similar to that shown in Figure 4.9 for just Red Bug Slough, were assessed. However, those outflows did not include baseflow components. Applying Equation (13), baseflow has been estimated for the outflow from the whole Lakes basin and the baseflow at the outfalls from each individual lake was still missing. In lieu of a better method, total baseflow for the basin was partitioned proportionally to the area of each subbasin. Such that 9.02% of the total baseflow was assigned to the Lake Mirror subbasin, 34.11% was assigned to the East Clark Lake subbasin, 10.94% was assigned to the West Clark Lake subbasin, and the remaining 45.92% was assigned to the Red Bug Slough subbasin. Such a division of total baseflow tacitly assumes that the perviousness of all four subbasins was similar.

The method used to partition the total baseflow applied the same damping effect for all four outflows. However, as the daily flows were aggregated into monthly volumes, this should not cause significant error.

Because the lakes are arranged in series, and do not act independently, both the baseflow assigned to the Lake Mirror subbasin and the baseflow assigned to the East Clark Lake subbasin has been added to surface runoff estimated for the East Clark Lake subbasin to obtain the total discharge from East Clark Lake. Similarly, baseflows assigned to the Lake Mirror subbasin, East Clark Lake subbasin, and West Clark Lake subbasin, were added to the surface runoff estimated for the West Clark Lake basin to obtain the total discharge from West Clark Lake. Lastly, the entire baseflow was added to the surface runoff from Red Bug Slough. The estimates of total monthly outflows from all four lakes are provided in Table 4.4. Those estimates were inserted into the water continuity Equation (1) as discharges *Out* from the lakes, and as concentrated inflow, *In*, to East Clark and West Clark Lakes.

Table 4.4. Estimates of Monthly Discharges from Lake Clark

Calculated monthly total discharges from four lakes (cubic feet)				
Month	Lake Mirror	East Clark	West Clark	Red Bug S.
	cf	cf	cf	cf
January	579,080	2,869,478	3,729,410	6,523,004
February	392,001	1,554,503	1,931,704	3,340,592
March	673,801	2,726,528	3,396,586	5,833,350
April	816,719	3,405,853	4,234,235	7,324,100
May	1,602,767	6,951,151	8,659,498	15,252,615
June	7,556,682	33,764,215	41,989,802	74,396,440
July	1,361,771	5,585,188	7,015,716	12,070,084
August	2,425,180	9,589,428	11,756,925	19,996,549
September	2,298,580	10,020,805	12,565,889	21,701,945
October	605,508	2,541,632	3,189,236	5,613,382
November	751,582	3,240,202	4,042,605	7,155,678
December	1,532,767	6,731,181	8,382,825	14,786,148

The outcomes tabulated in Table 4.4 are shown in Figure 4.11. It is worth noting that the estimated total discharge from Red Bug Slough shown in Figure 4.11 is an exact replica of the total flows shown in Figure 4.10. The flows on both figures are depicted by brown.

Removal of Red Bug Slough from Further Analysis

Red Bug Slough is located downstream of West Clark Lake (the lake that was verified as an nutrient impaired water). To present, Red Bug Slough was included into this analysis for the purpose of estimating lateral inflows to the first three lakes (variables p_1, p_2, *and* p_3 in Figure 4.7) and the flows between those three lakes (variables q_1, q_2, and q_3 in Figure 4.7). As the reader recalls, none of those flows has been measured. The only data available for the calibration of the models were flow measurements at the outlet of the Lakes basin, which is downstream of Red Bug Slough. For this reason, the subbasin of Red Bug Slough was included into the hydrologic system being analyzed. After completing the assessment of flows participating in the water budget for the three upstream lakes (Equation (1)), Red Bug Slough was no longer needed, and was excluded from the following analysis.

Direct Precipitation and Lake's Evaporation

The rainfall data were compiled from up to seven stations surrounding the Lakes basin (see Figure 4.4). Some of those stations went into operation sometime during 2003, so the compiled rainfall data were weighted average rainfalls from a variable number of stations during 2003. The total annual rainfall for the basin was estimated as 65.57," with annual distribution in 2003 depicted in Figure 4.10.

Water Resources of Sarasota County provided monthly average evaporation for the Tampa area published by IFAS at the University of Florida [5]. Those data were compared to pan evaporation data provided by Archbold Biological Station located about 80 miles east of the City of Sarasota. After confirmation of good correspondence of both sets of data, the first set was reduced by 20% for the pan coefficient, which is expected to be 0.8 for Central Florida, and used to calculate water losses from each lake due to evaporation. Monthly precipitation and evaporation for 2003 were shown in Table 4.5.

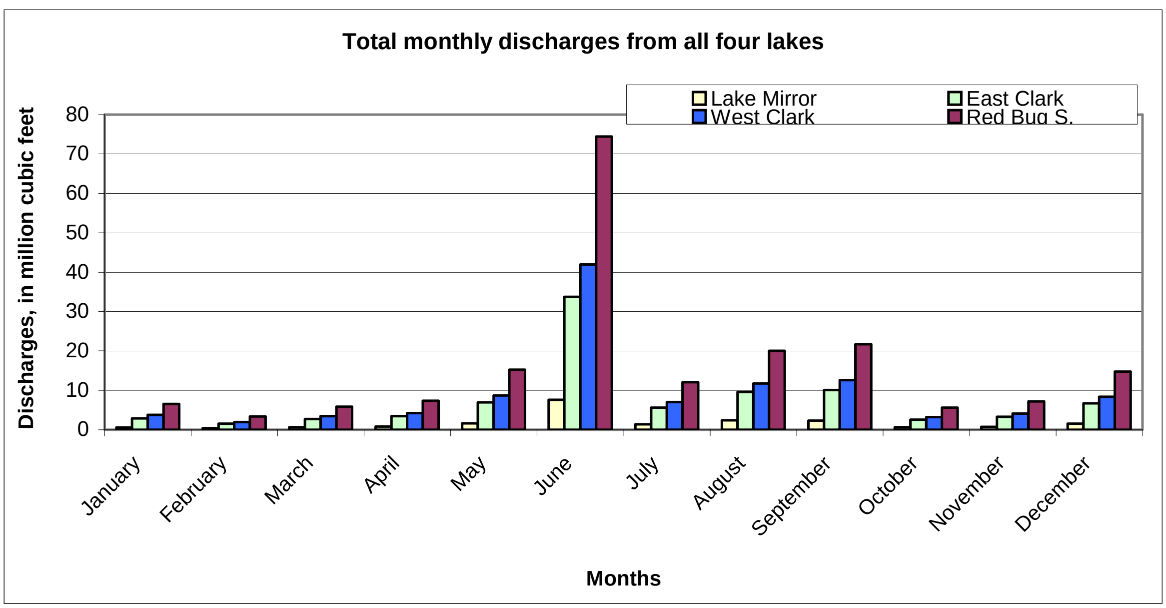

Figure 4.11. Discharges from four lakes in 2003 assessed by mathematical model

An average area of three lakes in the study area are 711,455 sq. ft for Lake Mirror, 452,743 sq. ft for East Clark Lake, and 374,540 sq. ft for West Clark Lake. Because the sides of all the lakes are steep, no correction for water stage oscillation during the annual cycle was made. Monthly volumes of accretion to water surface from precipitation and uptake by evaporation were shown in Table 4.6.

Response of Lakes to the Rainfall and Estimation of Water Stages

The last term in Equation (1) that needed to be evaluated was the volume of water detained in the lakes at the beginning and at the end of each month. The development of a TMDL for nutrients for West Clark Lake commenced with no information allowing such an evaluation.

Table 4.5. Monthly Estimates onto and Evaporation from Lake Clark

Monthly sums of rainfall in 2003 and average evapotranspiration (in inches)												
	Jan	Feb	Mar	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
rainfall	1.16	2.19	3.14	2.87	4.41	20.51	5.99	10.29	7.37	2.18	2.01	3.45
evap.	2.70	3.27	4.48	5.56	6.29	5.87	5.68	5.32	4.80	4.32	3.18	2.61

Collection of data began with delineation of bathymetry of all three lakes using a Si-Tech depth recorder and developing functions for ‘detention volume – water stage’ with the use of ArcGIS. The areas of depths with one-foot interval were calculated with GIS. The bathymetry maps and dependence of volume on water stages are included in Appendix B.   At the time the bathymetry was measured, water stages were relatively low. Therefore the functions ‘detention volume – water stages’ were extrapolated for two extra feet using the Taylor series for functions with one variable [8].

Table 4.6. Estimates of Volume of Rainfall Falling Directly on Lake Clark and Evaporation from the Surface.

			Rainfall falling on lake's area (cubic feet)									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lake Mirror	70,890	133,835	191,891	175,390	269,502	1,253,400	366,059	628,839	450,393	133,223	122,834	210,835
East Clark	43,765	82,626	118,468	108,281	166,383	773,813	225,994	388,227	278,060	82,248	75,834	130,164
West Clark	36,206	68,354	98,005	89,578	137,644	640,153	186,958	321,169	230,031	68,042	62,736	107,681
				Evaporation from lake's surface								
Lake Mirror	128,062	155,097	212,488	263,713	298,337	278,416	269,404	252,329	227,666	204,899	150,828	123,793
East Clark	81,494	98,698	135,219	167,817	189,850	177,173	171,439	160,573	144,878	130,390	95,982	78,777
West Clark	67,417	81,650	111,863	138,830	157,058	146,570	141,826	132,837	119,853	107,868	79,403	65,170

Staff gauges were installed in each of those lakes on November 8, 2004. By courtesy of Mr. John Ryan of Water Resources in Sarasota County, the water stages were recorded for over seventy days during November 2004 and February 2005. Mr. Jeffrey Banner of Environmental Resources of Sarasota County provided the needed climatic data for the same period. In effect, our analysis of water stages and rainfalls and semi-empirical functions for those lakes were developed. Those functions allowed estimating water stage in the lakes based on past rainfall. These estimates should not be expected to be of high accuracy since water stage in a lake is determined also by other factors than those used in our analysis. An average error of water stage predicted by the developed model was of the order of 0.5 inch (0.04 ft).

Each of these lakes was viewed as a storage element that satisfies the continuity equation

$$I - Q = \frac{\Delta S}{\Delta t} \tag{15}$$

However, storage *S* was related to discharge *Q* by a linear function [compare it with Equation (10)]

$$S = k\,Q \tag{16}$$

Such a simplification is supported by the previous finding that the optimal value of parameter *m* in Equation (10) for these lakes is one.

In the book *Applied Hydrology*, discharge is often related to the water stage in what is called a *rating curve* or *stage – discharge relation* [9]

$$Q = b\,(H - \hat{H})^n \tag{17}$$

In this equation, *H* denotes the water stage, and *b*, $\hat{H}$, and *n* are parameters to be adjusted to the particular outfall.

After elimination of storage *S* and discharge *Q*, the Equation (15) becomes a linear ordinary differential equation

$$I - b(H - \hat{H})^n = (k\,b)\frac{d}{dt}(H - \hat{H})^n \tag{18}$$

with the following analytical solution

$$(H - \hat{H})^n = [(H_0 - \hat{H})^n - \frac{I}{b}]\, e^{\frac{-t}{k}} + \frac{I}{b} \tag{19}$$

From this solution, daily water stages, H, were calculated for each lake. At each daily step, the variable H_o assumed the value equal to the water stage from day before with time step, t, being one day. Input I was the surface runoff predicted by the SCS CN method plus the discharge from the upstream lake, estimated by Equation (17). The parameters of the model, b, $\hat{H}$, and n, were adjusted to minimize the sum of absolute differences between measured and simulated water stages for the period of record, which was over seventy days.

Equation (19), approximated the measured water stages that were collected from the limited (73 – day) period quite well. However, during any annual cycle, the minimum water stage at which the discharge from a lake, $\hat{H}$, may occur can be modulated by the actual distribution of rainfall and evaporation. To make Equation (19) applicable throughout any year, parameter $\hat{H}$ was subjected to the subsequent adjustment

$$\hat{H}' = \hat{H} + h_o \sin(\alpha - \alpha_o) \tag{20}$$

In this equation, parameter

$$\alpha = 2\pi(\frac{D}{365}) \tag{21}$$

converts each calendar day, D, into an angle in radians, and h_o and α_o are two additional parameters which values were apprised to minimize the sum of absolute differences even further. The variable term in Equation (20) should be considered as a small additional component that oscillates in time like a sine function. A portion of the measured and predicted water stages in West Clark Lake are shown in Figure 4.12. The high stage that occurred on Christmas 2004 was not measured, so the actual peak is not known.

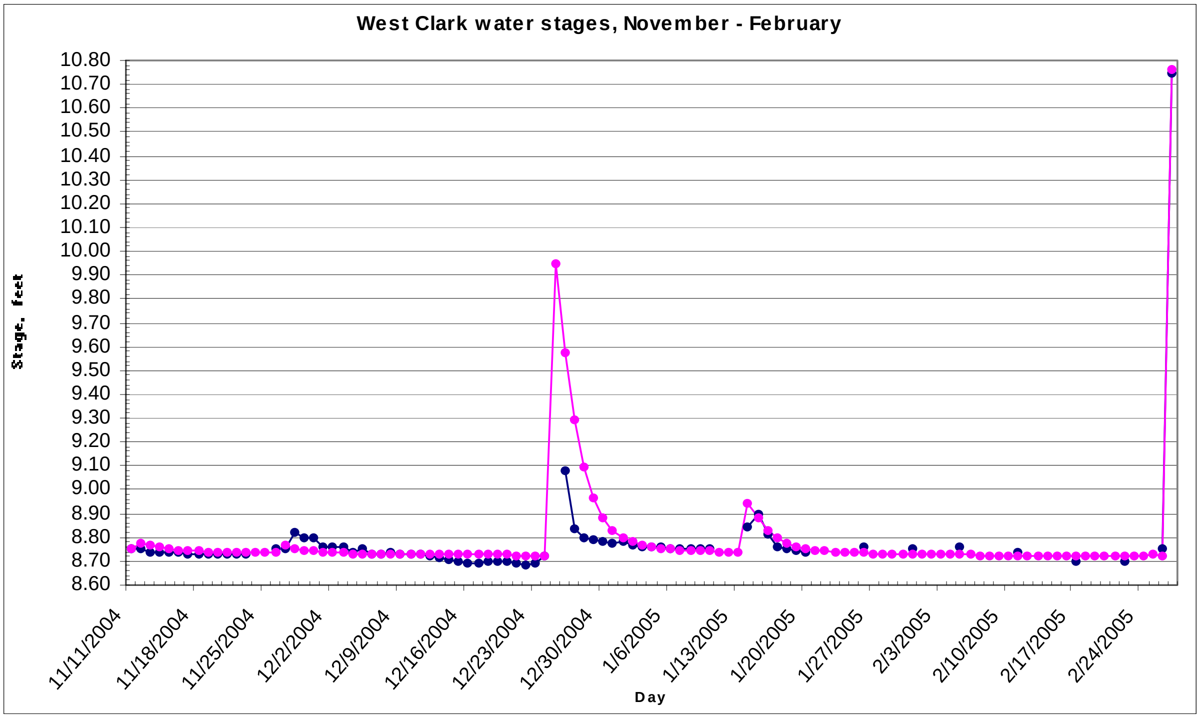

Figure 4.12. Water stages measured (black dots) in West Clark during period 11/11/2004 – 27/2/2005 and predicted by model (pink dots).

Estimate of Ground water Interaction with the Lakes

Given all the previous information, the ground water inflow component, *GW*, in the water continuity Equation (1) could now be determined. The calculations were conducted for the 12 months of 2003 for all three Lakes (Mirror, East Clark, and West Clark). The accuracy of the assessment is strongly dependent on the accuracy of the prediction of the other components of the water budget in the lakes. Therefore, for example, simplification of dynamically changing volumes of water detained in a lake to the steady-state case would drastically change ground water volumes, and possibly even the direction of flow.

The ground water component proved to be the predominant source of water in both Mirror Lake and East Clark Lake. The predictions show that for the one year of this analysis (2003), ground water exceeded any other source of water for Lake Mirror and East Clark Lake. Only for West Clark Lake did ground water give way to inflow from the upstream lakes. In our opinion, this was due to the area of the East Clark Lake subbasin being substantially extended as a result of urbanization. Tables containing the results for surface runoff, inflows from upstream lake, and losses due to evaporation, discharges, ground water inflow, and change in water volume detained in the lakes are provided in Appendix C.

Nutrient Mass Balance Methodology

Three water quality parameters were considered in the analysis, that is total phosphorus (TP), total nitrogen (TN), and chlorophyll a (Chla). Concentrations of these parameters are used to determine the trophic state index (TSI) that is used to classify a waterbody.

The mass balance equation was formulated as follow:

Sedimentation - internal load = point source incoming load + nonpoint source incoming load + ground water load + rainfall load – export load - increase of suspended mass

A spreadsheet model was developed that collected all previously assessed water components, estimated pollutant loads (TN and TP) from subbasins, ground water, and septic tanks and predicted loss of pollutants due to settling. Additionally, with nutrient concentrations and hydraulic parameters of the lake estimated from the mass balance equation, a spreadsheet model was used to subsequently estimate the chlorophyll a concentration and eventually the TSI. Generating a mass balance for each month and each lake, that spreadsheet model was run 36 times (three subbasins and 12 months in a year) for *the current loading* scenario.

Diffuse pollution was estimated by a loading function model (see for example [12]). The model is based on the transport of dissolved nutrients by water runoff and the yield of sediment-attached nutrients by sediment delivery. The dissolved nutrient load from each source area, i.e. land use category, is

$$LD = 28.314 \times 10^{-6}\, Cd\, SR \qquad (22)$$

where

LD = nutrient load (kg)

Cd = average nutrient concentration in runoff (mg/L)

SR = surface runoff estimated by a model like SCS CN (cu feet)

Estimates of average nutrient concentrations, also called Event Mean Concentrations (EMC), followed findings of Environmental Research & Design, Inc. [10]. Missing parameters for Urban Open land use category were added from the User's Manual of Watershed Management Model [11]. The complete set of EMCs applied to this project is presented in Table 4.7.

Table 4.7. Event Mean Concentration for nitrogen and phosphorus for Southwest Florida

Land Use/Cover	**Event Mean Concentration (mg/L)**	
	TN	TP
Forest/Rural Open	1.090	0.046
Urban Open	2.090	0.230
Agricultural	2.320	0.344
Low density residential	1.640	0.191
Medium density residential	2.180	0.335
High density residential	2.420	0.490
Highways	2.230	0.270
Water	1.600	0.067
Rangeland	1.090	0.046
Wetlands	1.010	0.090

The contribution of nutrients from septic tanks followed the Generalized Watershed Loading Function (GWLF) model [24]:

$$SL = 0.001\, a\, d\, (e - u) \qquad (23)$$

where

SL = the monthly nitrogen load to ground water from normal system (kg)

a = population served for each system

d = number of days in a given month

e = per capita daily nutrient load in septic tank effluent (g/day)

u = per capita daily nutrient uptake by plants (g/day)

Effluents from normal systems infiltrate into the soil and enter the shallow saturated zone. Effluent nitrogen is converted to nitrate and except for removal by plant uptake, the nitrogen may be transported to the nearest waterbody by ground water discharge. Conversely, phosphates in the effluent are adsorbed and retained by the soil and hence normal septic systems provide no phosphorus loads to surface water. In these calculations, after Haith *at al.* [24] default values of 12 g/day for per capita daily nitrogen load in septic tank effluent and 1.6 g/day for per capita daily nitrogen uptake by plants during growing season were used. In this part of Florida, the growing season is assumed to be all year long, following the suggestion of Dr. Thomas Obreza from Soil and Water Science, University of Florida (personal communication, 2/16/2005).

Normal septic systems are generally some distance from water bodies and their effluent mixes with other ground water before entering a surface waterbody. Monthly nutrient loads are thus proportional to ground water discharge to the stream or lake. The portion of the annual load delivered in a given month, is equivalent to the portion of ground water discharge which occurs in that month,

$$DS = \frac{GW \sum_{1}^{12} SL}{\sum_{1}^{12} GW} \qquad (24)$$

Here *DS* is the nitrogen load from septic tanks and *GW* is ground water discharge in a given month.

Sarasota County provided a list and map of new and repaired septic tanks in the Philippe Creek basin. Using GIS, a map of the study area was overlaid on a map of septic tank distribution. In total, 51 septic tanks were counted in the Mirror Lake subbasin, 149 septic tanks in the East Clark Lake subbasin, and 52 septic tanks in the West Clark Lake subbasin (Appendix D). Additionally, the City of Sarasota website http://www.epodunk.com/cgi-bin/housOverview.php?locIndex=8905 provided an average household size of 2.12 people in the study area, according to the 2000 Census. These numbers were used in our calculations.

The nutrient budget model requires that the loss of mass due to settling be determined and subtracted from mass of nutrients suspended in the water of a lake. The primary parameter of such a model is a first-order reaction (loss or trapping) rate, k, which provides an estimate of the ability of a lake to remove nutrients from the water column and trap them in the sediment. In most instances, it has been found that the trapping parameter, k, is a function of the lake's mean depth, H, hydraulic detention time, τ, (also called *residence time*), and the influent nutrient concentration, C_p or C_n. Based on an analysis of Florida lakes, Reckhow developed regression equations for this first-order reaction rate [12]. During calibration of the water quality models, it was found that both equations over predicted losses due to settling and no match to the measured nutrient concentrations was possible. Subsequently, the ability of different models based on volumetric loading were tested

$$k = a\left(\frac{L}{H}\right)^{n} \tag{25}$$

where L is the annual nutrient (phosphorus or nitrogen) loading per unit of lake surface area, mg m^{-2} y^{-1}, H is lake's average depth, and parameters a and n were determined after analyzing a few hundred natural and artificial lakes surveyed by EPA (Bachmann). The model for the total phosphorus, developed and described by Canfield and Bachmann [22], predicted an excessive amount of the phosphorus losses to the sediment and was excluded from further analysis. Instead, the settling loss rate was approximated based on the flushing rate [13]

$$k = \frac{1}{\sqrt{\tau}} \tag{26}$$

where τ is residence time in years. For consistency of units, the parameter *k* was divided by 12 to fit the analysis of water quality in the Lakes which was conducted on a one-month interval.

Since the time when Vollenweider recognized the importance of nutrient inputs in determination of trophic state, a number of empirical models have been developed to predict total phosphorus concentration in lakes. Yet, little effort has been expanded on developing similar models for the other important element, nitrogen. Bachmann [21] analyzed over 200 EPA-surveyed lakes and provided a number of statistical models that related the concentration of nitrogen to annual load and lake's depth. The model selected for TMDL development for West Clark Lake was in a form similar to Equation (25) with depth H = 1 and the parameters a = 0.00161, and n = 0.709. Such function Bachmann named this function the *areal nitrogen loading* model.

Unlike phosphorus with only one valence state, nitrogen is found in four different states of oxidation. One of these, nitrogen gas, is relatively inert and is not included in the total nitrogen measurement. However it can be incorporated into the cycle through biological fixation by blue-green algae or can be lost from the biological cycle through the action of denitrifying microorganisms on nitrates. Additionally, nitrogen can be lost to sediment or can be resuspended from sediment to the water column. Therefore, Bachmann rightly names parameter *k* in Equation (25) the *attenuation coefficient,* reserving the traditional name *settling loss rate* to phosphorus.

Chapra generalized the Vollenweider model and showed that the first-order settling rate is related to the apparent settling velocity, ν, by [13]

$$\nu = k\,H \tag{27}$$

Using this equation, monthly losses of nutrients due to settling (kg) were estimated as

$$Settling = \nu A_s C_l / 12000 \tag{28}$$

where A_s is the lake's surface area in meters and index i refers either to nitrogen or phosphorus. In the two previous equations (27 & 28), apparent settling velocity should be understood as the effective velocity with which particles of phosphorus and nitrogen fall to the bottom.

The prediction of chlorophyll in a lake has always been a challenging task because most of the controlling factors are hard to quantify. In a first attempt, the empirical approach of William Walker was adopted [14] that relates chlorophyll to light, and flushing rate (flushing rate is a reciprocal of residence time). While Walker's approach targets annual average conditions, our need to create a monthly water and mass balance led us to try it on a monthly basis. Having measured chlorophyll level in nine months of 2003, it was possible to calibrate Walker's model, but even then the model was unable to reproduce the measured chlorophyll in April, May, and December. Eventually, a regression equation that relates chlorophyll to the nutrient concentration and monthly-average temperature, T, was adopted as a better fit to the nine monthly chlorophyll concentrations measured in West Clark Lake.

$$Chla = a\,C_{TP} + b\,C_{TN} + c\,T + d\,T^2 \qquad (29)$$

A comparison of the results using Equation (29) to the nine-months of data is shown in Figure 4.13.

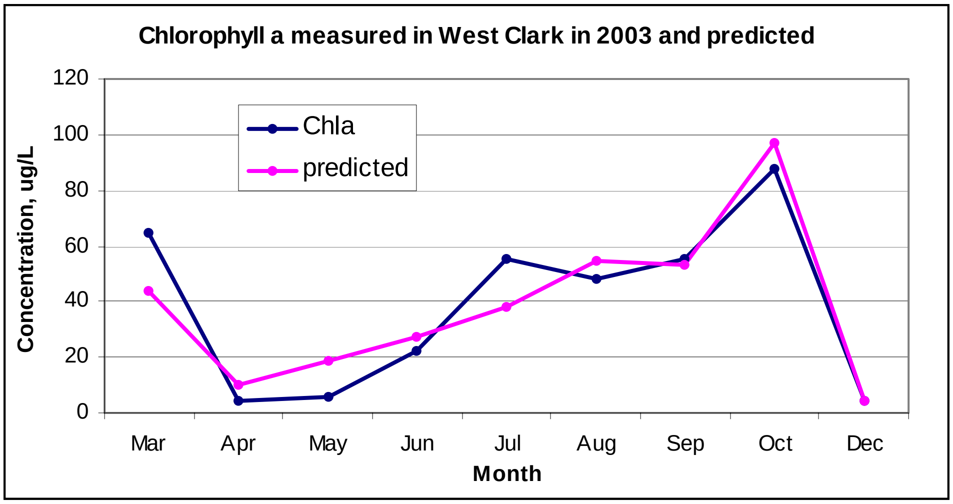

Figure 4.13. Chlorophyll a measured in nine months of 2003 and predicted by simple regression equation

The use of this equation is limited to West Clark Lake with the exclusion of January, in which temperature dropped below the range of temperatures used in the regression.

The coefficient of determination R^2 (which is the correlation coefficient squared) related to Equation (29) reached 0.85. But even so, the coefficient *b* in the equation, standing at the nitrogen concentration C_{TN} was negative. Given this result, with all the remaining variables kept constant, a higher concentration of nitrogen reduced the concentration of chlorophyll determined by that equation. As a best guess, this unexpected outcome is an artifact of the very low number of samples taken from West Clark Lake during 2003. West Clark Lake is a small lake surrounded by roads and grasses maintained by the local community. In any sporadic sampling taken from such a lake, the concentration of chlorophyll a may be related more closely to the nutrient concentration in the past weeks rather than to the current concentration of the nutrients that can vary with each rainfall event. As a result of finding a negative coefficient for b in the regressions equation we decided that it should not be used to assess either the background condition or for the prediction of the required load reductions to attain the TMDL. Instead, of using the regression equation to predict chl a on the monthly results, Walker's model would be used on the annual average results from the spreadsheet model for nutrients.

Role of Bird Populations

There is an active bird rookery in the middle of Mirror Lake which likely contributes a significant nutrient load that results in high productivity (algae) in the Lake. This system is likely have high TSI values as long as the bird rookery is present.

Several research projects have been conducted to estimate pollutant loading from waterfowl. Manny et al. [15] estimated that mature Canada geese defecate an average of 28 times per day, with an average dry weight of 1.17 grams/dropping. Analysis of the goose droppings indicated a phosphorus content of approximately 1.34% and a nitrogen content of 4.38% on a dry weight basis. As a result, a single goose contributed approximately 0.49 grams of total phosphorus and 1.57 grams of nitrogen to Lake Michigan each day. It was observed that swans and geese are similar in the production of feces.

Unfortunately, we could only find reliable literature-based pollutant loading rates for species of swans and geese. Environmental Research Design (ERD) in its nutrient analysis of Lake Morton (near Lakeland, Florida) decided to estimate mass input from waterfowl based upon the use of feed material by the City of Lakeland's Parks Department [16]. In this case, it was assumed that inputs and outputs were approximately equal for a mature waterfowl on an annual basis. ERD concluded that the feed provided for waterfowl at Lake Morton contained approximately 776 kg of total nitrogen and 164 kg of total phosphorus per year. Dividing these loads into the 573 birds counted at Lake Morton, translated into 1.354 kg of nitrogen and 0.286 kg of phosphorus per waterfowl per year. Bird counts performed in Lake Morton included, but were not limited to, swans, herons, ducks, geese, and egrets. It may be expected that under the feeding program of the Park Department, the waterfowl consumed a quantity of food that was on the upper limit of their need for food. Consequently, 1.354 kg of nitrogen and 0.286 kg of phosphorus should also be considered as an upper limit of nutrient production by one average (in sense of species) waterfowl.

The estimates made by ERD may be too high for a good reason. Gere and Androkovics investigated the feeding patterns of a colony of 1500 pairs of Cormorants in Hungary and found that *less* than the consumed mass of phosphorus and nitrogen was excreted [17].

Several other studies revealed much lower loads of nutrients ascribed to waterfowl. For example, Andersen et al. evaluated the bird contribution to loading of nitrogen and phosphorus to constructed wetlands in southern California [18]. Their estimates of maximum input by birds were only 41.8 g of nitrogen and 16.8 g of phosphorus per bird per year. However, the lower limit of similar estimates resulted from the studies conducted by Marion et al for Lake Grand-Lieu in France [19]. After dividing mean mass of in lake loading by the total bird population they arrived at 3.89 g of nitrogen and 1.31 g of phosphorus per bird per year.

Due to a lack of reliable data on the waterfowl nutrient contribution to Mirror Lake (and subsequently the downstream lakes), the following estimate was conducted. By courtesy of John Ryan of Sarasota County, a count of birds and waterfowl at Mirror Lake became available (from a small number of observations). Estimates of the weight of each representative of each species were made based on values provided by websites listed in Appendix G. Following the previous studies (see for example [20]), it has been assumed that the nutrient contribution of waterfowl was *proportional* by body weight to that of Canadian geese. Unfortunately, the weight of a Canadian goose varies in the widest range of all waterfowl that were on our list, i.e. between 3 and 12 lbs. Following [20], a weight of 2.56 kg (i.e.5.63 lbs.) has been assumed for an average goose. Table 4.8 summarizes our predictions of nutrient loads to Mirror Lake ascribed to the waterfowl. The total loads, shown in the bottom row, were uniformly distributed throughout 2003, although food availability and migration patterns may impose daily or seasonal variation to the loading.

Water Quality Data and Calibration of Mass-Balance Models

In 2003, West Clark Lake (Lake) was sampled once a month for the concentration of TP, TN, and chlorophyll a in months March through October. Additionally, the Lake was sampled twice in December.

Table 4.8. Bird species identified at Lake Mirror, count, and predicted nutrient contribution. Weight ratio is related to average Canada goose

Species	Count	Weight (lbs.)	Weight ratio	Annual nutrient production (lbs.)	
				TP	TN
Double Crested Cormorant	265	3.70	0.66	68.64	219.94
Anhinga	35	2.97	0.53	7.28	23.32
White Ibis	312	2.00	0.36	43.69	139.97
Glossy Ibis	148	1.34	0.24	13.91	44.55
Common Egret	3	2.25	0.40	0.47	1.51
Snowy Egret	42	0.81	0.14	2.39	7.65
Black-crowned Night Heron	1	1.81	0.32	0.13	0.41
Little Blue Heron	16	0.75	0.13	0.84	2.69
Louisiana Heron	1	0.69	0.12	0.05	0.15
Tri-colored Heron	1	0.81	0.14	0.06	0.18
Total	**824**			**137.45**	**440.39**

The concentrations of nutrients found in West Clark Lake, and shown in Figure 4.16, created a serious challenge since the pattern of variability of phosphorus and nitrogen was not quite related to one another as one might expect (Figure 4.14). Instead, the concentrations of phosphorus measured in the Lake in 2003 were related inversely to the concentrations of nitrogen (Figure 4.15).

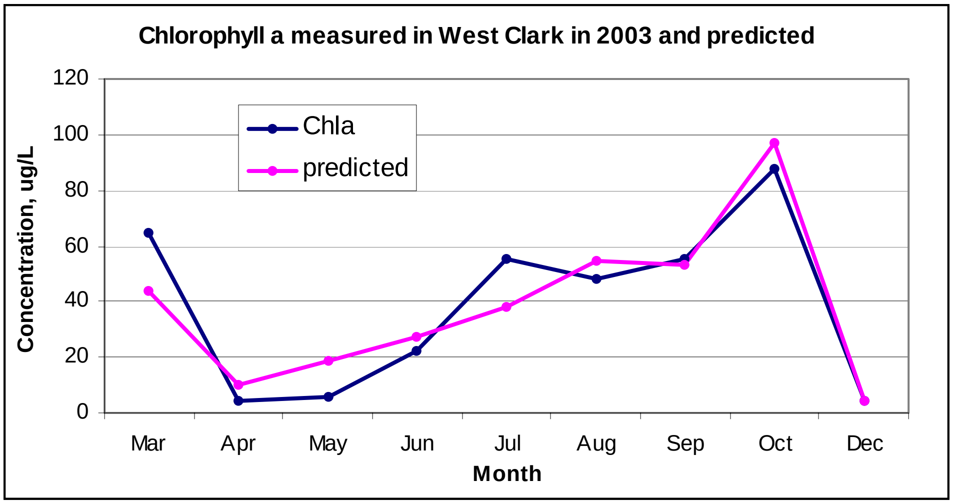

Figure 4.14. Annual average total nitrogen concentrations and annual average total phosphorus concentrations in several Florida lakes (after [25])

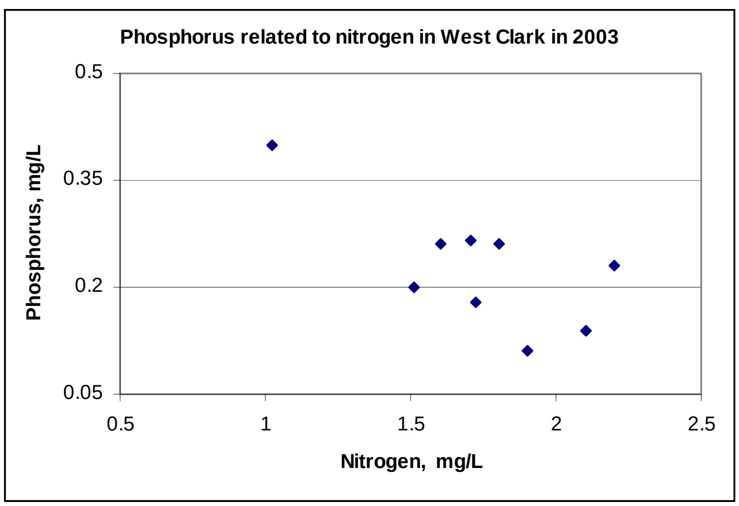

Figure 4.15 Nutrient concentrations measured in West Clark during 2003

Comparing Figures 4.13 and 4.16, it does not seem to be clearly determined by which nutrient the Lake is limited. TN/TP ratio for nine months in which samples were collected is 9.6, 9.6, 15.0, 17.3, 6.9, 7.5, 6.2, 2.6, and 6.4. From these numbers it appears that the Lake was primarily N - limited, with some co-limitation. In March and April, TN/TP had the same value of 9.6. However, the chlorophyll concentration rose sharply in

March and dropped in April (see Figure 4.13). Perhaps relatively warm March (74.5 degrees) and drop of temperature in April (70.3 degrees) boosted or limited the growth of algae in the Lake. Concentrations of chlorophyll a measured in West Clark Lake and the TSI calculated from measured nutrients are shown in Figure 4.17. Out of nine

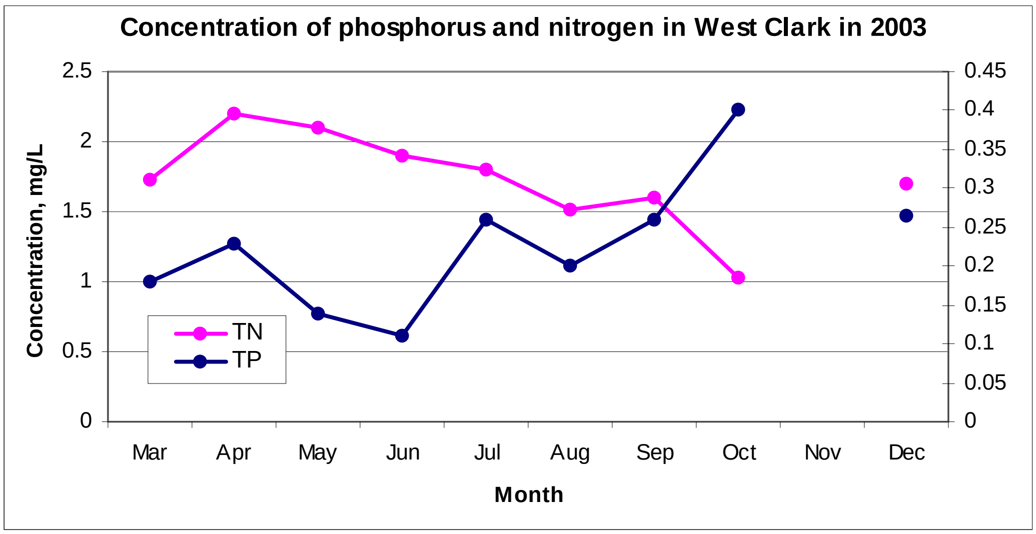

Figure 4.16. Concentration of phosphorus and nitrogen measured in West Clark in 2003

months sampled, only three, April, May, and December, had trophic index below the IWR threshold of 60. For the year 2003, the trophic state index, calculated from the four seasonal TSI's, was **69.35** indicating that West Clark Lake is impaired for nutrients. With TN/TP < 10, the formula for TSI categorized that lake as nitrogen limited.

Our calculations of TSI were extended to Mirror Lake and East Clark Lake in case Sarasota County is interested in the water quality issues for these two upstream lakes. Please recall that those lakes were never sampled by DEP, therefore the determination of the TSI was based entirely on results simulated by the spreadsheet models previously described. For Mirror Lake, the annual-average TSI was determined as 68.6 and for East Clark Lake the annual-average TSI was 70.0. These results should be viewed only as approximate numbers, especially as the chlorophyll concentration was calculated from Equation (29) with the coefficients calibrated for West Clark Lake. All annual-average TSI's provided in this report for the current condition are based on averaging the quarterly TSI values.

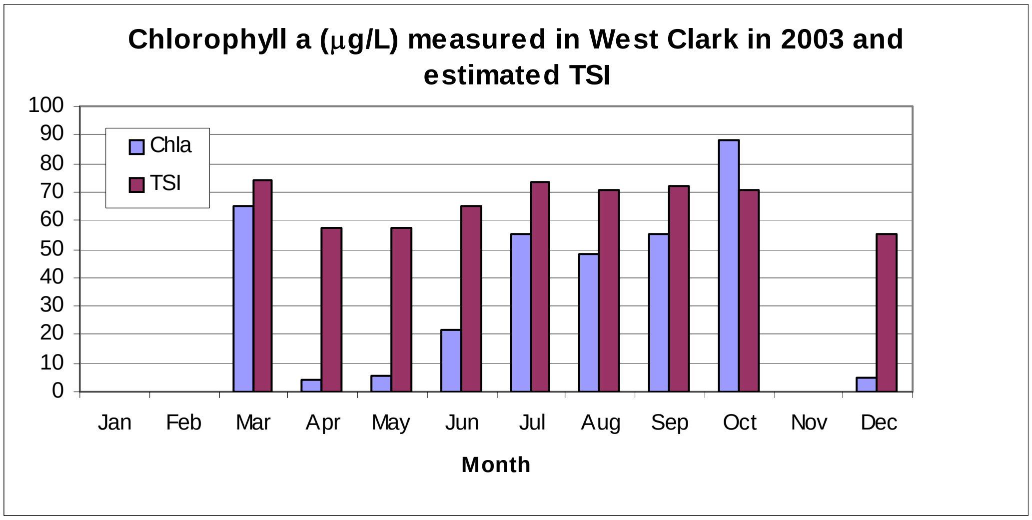

Figure 4.17 Chlorophyll a measured in West Clark in 2003 and TSI determined from concentration of phosphorus, nitrogen, and chlorophyll

The nutrient balance in the Lakes was calculated using separate spreadsheet models, one for each month and for each lake, altogether 36 separate spreadsheets. The spreadsheets were interrelated because the concentrations at the end of one month were used as the initial conditions to the following month, and the mass of nutrients exported from each upstream lake was included as an input to the downstream lake.

As during the determination of the water budget and the calculation of the mass balance of nutrients in the Lakes, the primary unknown was related to ground water. In the early stages of computation it became clear that the closest available ground water nutrient concentrations (from a few shallow ground water wells located a few miles outside the basin boundary of WBID 1971) was not in our opinion representative of the shallow aquifer beneath the Lakes. Also, it appears reasonable that the nutrient concentration of the ground water entering the Lakes probably varies with time and should be adjusted according to the time step used in the analysis (in this case on a monthly basis). To calculate a monthly nutrient budget for West Clark Lake (the only lake with nutrient data), concentrations of TN, TP, and Chl a had to be assigned to the months with missing data. There were no data for January or February in the first quarter of 2003, therefore, the first quarter TSI was based on the data collected for March. There were no data collected in November, therefore the forth quarter TSI was based on the arithmetic average of the concentrations from October and December.

The estimated nutrient concentrations used to represent the inputs from the ground water are provided in Table 4.9. All the uncertainties in estimating surface flows in the Lakes, the Lakes depths and volumes, climatic data, areal loading, waterfowl nutrient production, septic tanks, and losses due to settling are incorporated into the concentrations provided in Table 4.9.

Table 4.9. Concentration of nutrients in ground water estimated from mass balance conducted for each month for West Clark Lake

Pollutant	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Phosphorus	0.25	0.38	0.30	0.45	0.10	0.00	0.58	0.27	0.49	1.02	0.52	0.40
Nitrogen (no septic tanks)	0.65	0.53	0.45	1.95	1.06	0.93	0.60	0.00	0.22	0.00	0.00	0.72
Nitrogen (from septic tanks)	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
* Nitrogen (total)	1.87	1.75	1.67	3.17	2.28	2.15	1.82	1.22	1.44	1.22	1.22	1.94
* including loads from septic tanks												

The ground water concentrations adjusted during model calibration disclose the possible variability of nutrient content from one month to another. In particular, the zero level of phosphorus in June may not be a realistic value. However, June 2003 was an exceptionally difficult month to model considering that 20.5 inches of rain were recorded in the Lakes basin. A possible explanation of this anomaly is that the sample was taken on June 9th after a period of relatively low rainfall. Only 9 percent of the monthly rainfall occurred during first nine days of June. On the other hand, the phosphorus concentration rose to an unexpected high of 1.02 mg/L in October with no rational cause. The concentrations of nutrients in the shallow ground water aquifer were estimated from the previously described mass balance equation. In October, the measured phosphorus concentration in West Clark Lake was 0.4 mg/L. As Table 4.7 shows, only highly dense residential areas can produce runoff so rich in phosphorus. However, high density residential area occupies only 16% of the West Clark Lake subbasin, with the remaining 84% of land discharging surface runoff that should be less rich in phosphorus. To match the 0.4 mg/L of phosphorus measured in the Lake as the monthly-average concentration in a well-mixed lake, the ground water concentration had to be elevated to the unusually high value of 1.02 mg/L. We verified that in October, the only sample was taken immediately after 0.3" of rainfall, in close proximity to the Lake's inlet and to the discharge from a stormwater pond (for location see Figure 4.3). All samples were collected at ~ 0.2' below the water surface. There is good reason to believe that the measured concentration was more representative of surface runoff from the immediate vicinity of the station in West Clark Lake and may not reflect the monthly average concentration of phosphorus in the Lake as a whole.

East and West Clark Lakes are hydraulic systems that respond to rainfall rapidly. This can be deduced from the steep recession limb of a storm hydrograph (please see hydrograph of discharge in Figure 4.9). In such small systems, the variability of pollutant concentrations can exceed the variability in larger waterbodies. A sample taken one day a month (at the edge of a lake near the inlet) may not adequately represent the lake's average concentration in that month.

In Table 4.9, nitrogen concentrations were provided in three rows. The top row represents ground water nitrogen concentrations without septic tanks. The middle row represents the ground water levels from septic tanks. The last row is the combined ground water concentration. Such separation of concentrations was a convenient way of evaluating the background condition of the Lakes (in which the impact of the population residing in the basin was removed).

The total estimated monthly nutrient load to West Clark Lake for current conditions was broken into various sources and is presented in Table 4.10. In this Table, the source "upstream inflow" represents all of the cumulative loadings of ground water, septic tanks, water fowl (Mirror Lake only), and surface water runoff from both Mirror and East Clark Lakes that enter West Clark Lake. The sources "Surface runoff", "ground water", and "septic tanks" represent only the loadings of these sources from within the West Clark Lake basin. From this analysis, 4,545 kg/year of TN and 553 kg/year of TP are imported from sources upstream of the West Clark Lake basin (Mirror and East Clark Lakes). The West Clark Lake basin contributes 1,280.5 kg/year of TN (645.7 from surface runoff, 417.6 from septic tanks, and 217.2 from ground water) and 200.2 kg/year of TP (90.5 from surface runoff and 109.7 from ground water).

Table 4.10. Estimated nutrients loads into West Clark Lake for Current Conditions

Estimated sources of nutrients to West Clark Lake (kgs)							
	Surface runoff		Septic tank	Ground water		Upstream inflow	
	TN	TP	TN	TN	TP	TN	TP
Jan	7.6	1	23.6	12.6	4.8	141.4	15.9
Feb	4.3	0.4	13.2	5.7	4.1	76.7	9.6
Mar	12.4	1.5	19.2	7.1	4.7	134.7	16.3
Apr	18.2	2.4	23.5	37.7	8.7	222.3	25.6
May	31.7	4.3	44.6	38.9	3.7	415.7	29.7
Jun	356.6	52.2	88.7	67.8	0	1810.9	148.5
Jul	24.8	3	32.8	16.2	15.7	285	46.5
Aug	67.2	9	41.2	0	9.1	429.4	57.1
Sep	73.7	10.3	47.9	8.7	19.3	458	79.5
Oct	5.9	0.6	19.4	0	16.3	106.2	35.4
Nov	8.7	1	24.7	0	10.6	130.3	33.9
Dec	34.6	4.8	38.8	22.5	12.7	334.2	55
Total	**645.7**	**90.5**	**417.6**	**217.2**	**109.7**	**4544.8**	**553**

Chapter 5: DETERMINATION OF ASSIMILATIVE CAPACITY

Nutrient enrichment and the resulting problems related to eutrophication tend to be widespread and are frequently manifested far (in both time and space) from their source. Addressing eutrophication involves relating water quality and biological effects (such as photosynthesis, decomposition, and nutrient recycling), as acted upon by hydrodynamic factors (including flow, wind, tide, and salinity) to the timing and magnitude of constituent loads supplied from various categories of pollution sources.

5.1 Critical Conditions

To evaluate nutrient impairment in a lake, a reference condition is needed. For lakes in Florida, the reference condition is represented by the TSI. West Clark Lake was included on the list of impaired waters because at least one annual mean TSI exceeded the IWR threshold during the verified period. For West Clark Lake, the TSI was 69.35 with an average color of 91 PCU in 2003 (the only year with data). In years with a mean color less than 40, the TSI threshold would be 40. In years with a mean color greater than 40, the TSI threshold would be 60. Since the annual TSI of West Clark Lake was greater than 60 (Figure 4.15), the Lake would be listed as impaired regardless of the color.

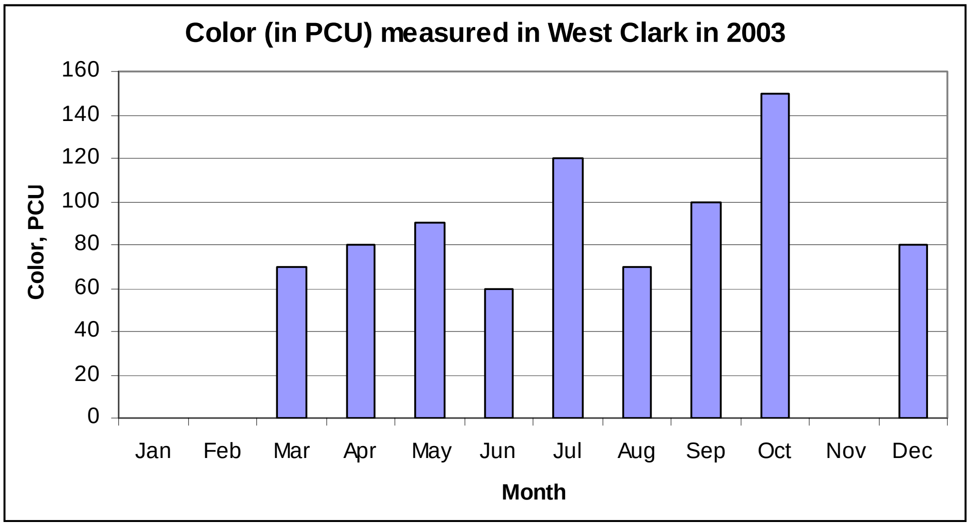

Figure 5.1 Monthly-average color in West Clark during year 2003 with annual average 91

5.2 Determination of Background

To evaluate the background condition for the Lakes, the current land uses listed in Table 4.1 under *urban*, *residential, agriculture*, and *transportation* categories were evaluated as *forest,* loading from septic tanks was set at zero, but the connections between West Clark Lake and East Clark Lake and Lake Mirror were preserved.

Under these background conditions, it is likely that the ground water inflow/outflow to the Lake was different from that of the current condition, which is highly impacted by urbanization of the basin. The water budget Equation (1) was used in a similar way as it was used to evaluate the current condition. The surface runoff for the background condition dropped to 69 percent of the annual volume estimated for the current condition, and ground water inflow dropped to 76 percent of the current volume. The latter estimate should be considered as a rough assessment at best since the parameters in the model for water stages in the Lakes, Equations (16) through (20), preserved the same values as were used for current conditions. A more realistic model would require solving the partial differential equation for unsteady flow of water in unconfined aquifer, so-called Boussinesq equation, with known boundary conditions, saturated hydraulic conductivity of the soil, drainable porosity, slope of aquifer's bed, accretion to the water surface, and water stages in the lake [see for example 23]. However, none of these parameters or data are available. The estimates of the components of the water budget used in this study are provided in Appendix F.

Background Mass Balance

Determination of the background condition of the Lakes required converting all human landuses to forest, eliminating waterfowl from Lake Mirror, and all septic tanks from the basin. These changes were incorporated into the spreadsheet models and used in a similar manner to the way the current condition was analyzed. The only exception is that Walker's model for prediction of Chl a was used on the annual average TN and TP concentrations predicted by the spreadsheet models.

Before the Lakes watershed was populated, the quality of ground water in the surficial aquifer was probably different from present. The quality of that ground water was not available to us. As the best approximation of background ground water quality, the concentrations established by the U.S. Eutrophication Survey, and quoted in [24], were substituted for the missing data. These data are mean concentrations computed from 12 monthly stream flow samples in watersheds free of point sources. Since such limited sampling is unlikely to capture nutrient fluxes from storm runoff, the stream flow concentrations were used to represent ground water discharges to streams. For an area in the above survey that was 80% forested, the concentration of TP was 0.0064 mg/L and the concentration of TN was 0.213 mg/L. For an area that was 88% forested, the concentration of TP was 0.006 mg/L and the concentration of TN was 0.193 mg/L. For an area that was 91% forested, the concentration of TP was 0.006 mg/L and the concentration of TN was 0.189 mg/L. These concentrations correspond to the subbasins of Lake Mirror, East Clark Lake, and West Clark Lake, respectively.

Table 5.1. Background Concentrations (annual average)

	TP (mg/L)	TN (mg/L)	Chl-a (ug/L)	TSI
Annual Average	0.016	0.61	7.7	43.9

The effect of eliminating septic tanks, and converting all human landuses to forest, was that the concentration of TP in West Clark Lake dropped from an annual average 0.23 mg/L (current) to 0.016 mg/L (background). Similarly, the current annual average concentration of TN of 1.7 mg/L dropped to 0.606 mg/L (background) and chl a was reduced from the current annual average of 43.66 ug/L to 7.7 ug/L. Finally, the current annual average TSI of 69.3 dropped to **43.9**. This number will be considered as the background TSI for West Clark Lake. In order to assess the sensitivity of the background TSI to changes in TP and chl a, a combination of other values was checked to determine the level that would result in a background TSI of 60. A background TP of 0.3 mg/L with a chl a of 40 ug/L would result in a TSI of 60 given a TN of 0.61 mg/L. By our analysis, even if the background TP and chl a were under estimated, the background TSI would not reasonably be expected to be greater than 60.

5.3 Determination of Assimilative Capacity

It should be recognized that the direct application of background as the target TSI would not allow for any assimilative capacity. The IWR uses as one measure of impairment in lakes, a 10 unit change in TSI from “historical” levels. This 10 unit increase is assumed to represent the transition of a lake from one trophic state (say mesotrophic) to another nutrient enriched condition (eutrophic). The Department has assumed that allowing a 5 unit increase in TSI over the background condition would prevent a lake from becoming impaired (changing trophic states) and reserve 5 TSI units to allow for future changes in the basin and as part of the implicit margin of safety in establishing the assimilative capacity. Since the background condition assessed resulted in a TSI of more than 5 TSI units less than 60, DEP will use a TSI of **60** as the target TSI for West Clark Lake.

Recall that during calibration, predications for chl a were needed for each month to recreate a year of data, this resulted in the use of a regression equation to predict monthly chl a, since Walker's model of chlorophyll was not suitable for monthly analysis. Since the TMDL will be for annual average conditions, we have returned to Walker's model for predication of annual average chlorophyll. Walker's model of chlorophyll growth [14] was applied (see Section *Nutrient Mass Balance methodology*.) Dr. Walker's idea was to relate chlorophyll to TP, TN, turbidity, and flushing rate

$$
\begin{aligned}
Xpn &= \{p^{-2} + [(n - 150)/12]^{-2}\}^{-.05} \\
Bx &= Xpn^{1.33} / 4.31 \\
G &= Zmix\,(0.14 + 0.0039\,Fs) \\
Chl\ a &= Cc\,Bx / [(1 + 0.025\,Bx\,G)\,(1 + G\,a)]
\end{aligned}
\tag{30}
$$

where

Chl a is chlorophyll a concentration in μg/L

p is phosphorus concentration in μg/L

n is nitrogen concentration in μg/L

Zmix is mean depth of mixed layer, m

Fs is lake's flushing rate, y^{-1}

a is nonalgal turbidity, m^{-1}, and

Cc is calibration coefficient.

The estimate of nonalgal turbidity was also provided by Walker as

$$a = S^{-1} - 0.025\,(Chl\ a) \tag{31}$$

In this equation, *S* is Secchi depth, in m, that was approximated as

$$S = Cs\ 16.2\ Xpn^{-0.79} \tag{32}$$

As Secchi depth was not measured in West Clark Lake, calibration coefficient *Cs* arbitrarily had to be one. Another model coefficient, *Cc*, was calibrated on the predicted concentrations of phosphorus of 0.24 mg/L, and of nitrogen of 1.86 mg/L as annual averages determined from the mass balance equation for West Clark Lake. *Cc* was set at the value 1.21 at which algorithm provided in Section 2.2 and attached to Walker's model determined TSI being 69.3. At this point, Equation (29) having parameters calibrated on measured concentrations of nutrients in West Clark Lake and Walker's model calibrated on annual average nutrient concentrations determined by our spreadsheet models, both (measured and predicted) having categorized West Clark Lake consistent with one another as a eutrophic lake with a TSI = 69.3. Interestingly, annual-average chlorophyll concentration determined by Walker's model was 30 μg/L, quite close to the 36 μg/L estimated from the monthly concentrations predicted by Equation (29).

Determination of Loading Capacity: Scenarios Evaluated

<u>Waterfowl in Mirror Lake:</u>
Reductions in nutrient loadings to West Clark Lake were simulated using the spreadsheet models beginning with the removal of waterfowl from Lake Mirror. In the background condition, the removal of waterfowl reduced the TSI by only 2 points. For the remaining scenarios, loadings from waterfowl were retained.

<u>Elimination of Septic Tanks from Mirror, East Clark and West Clark Lakes:</u>

As the next considered situation, the current condition was preserved in all basins, but all septic tanks in the three subbasins were eliminated. The annual-average concentration of phosphorus was unchanged from the current condition (0.23 mg/L), nitrogen dropped from 1.70 mg/L to 1.17 mg/L, and chlorophyll <u>a</u> dropped from 43.66 μg/L to 29.8 μg/L. The corresponding TSI dropped to the value of 64.3. The loading estimates remained unchanged from the current condition for TP from all basins (753.2 kg/y). TN loadings from all basins were reduced from 5825.3 kg/y to 5407.7 kg/y. This indicates that eliminating septic tanks without reductions in the nutrients in surface water runoff will not met the target TSI of 60. With septic tanks deactivated, the mass of nitrogen in the upstream inflow was reduced by 2786.4 lbs/y compared to current situation as it is seen by comparing the results in Table 5.1 to those in Table 4.10 but the target TSI of 60 was not attained.

Table 5.2. Predicted mass of nutrients (in kgs) incoming to West Clark Lake .after septic tank elimination in all three lake subbasins

Month	Nutrient Loads (Kgs)						
	Surface runoff		Septic tank	Ground water		Upstream inflow	
	TN	TP	TN	TN	TP	TN	TP
Jan	7.6	1	0	12.6	4.8	102.6	15.9
Feb	4.3	0.4	0	5.7	4.1	49.4	9.6
Mar	12.4	1.5	0	7.1	4.7	85.7	16.3
Apr	18.2	2.4	0	37.7	8.7	163.4	25.6
May	31.7	4.3	0	38.9	3.7	282.7	29.7
Jun	356.6	52.2	0	67.8	0	1482.7	148.5
Jul	24.8	3	0	16.2	15.7	193.2	46.5
Aug	67.2	9	0	0	9.1	289.0	57.1
Sep	73.7	10.3	0	8.7	19.3	314.3	79.5
Oct	5.9	0.6	0	0	16.3	54.4	35.4
Nov	8.7	1	0	0	10.6	57.7	33.9
Dec	34.6	4.8	0	22.5	12.7	205.8	55
Total	**645.7**	**90.5**	**0**	**217.2**	**109.7**	**3280.9**	**553**

Elimination of Septic Tanks and a Twenty Five Percent Reduction in Surface Water Runoff:

After several iterations of reducing nutrient loadings from surface runoff, it was discovered that a reduction of 25% in TN and TP loadings from surface runoff in both the upstream inflow (from Mirror and East Clark lakes) and from within the West Clark Lake basin, in combination with the elimination of septic tanks resulted in annual average TP of 0.217 mg/L, TN, of 0.1.018 mg/L and chl a of 19.41 ug/L. The resulting TSI was 59.7 (rounded 60). This should be considered as a conservative estimate, in which expected improvement of ground water quality and changes in the initial condition were not included. In this scenario, ground water loadings (minus septic tanks) remained at current condition levels. For this scenario, the current condition loadings of TP from within the West Clark Lake basin for surface water runoff were reduced from 90.5 kg/y to 68.12 kg/y, TP from ground water remained the same at 109.7 kg/y. TP from upstream sources [surface water runoff (25% reduction) plus ground water (no change)] was reduced from 553 kg/y to 493.36 kg/y. For TN, loadings from within West Clark Lake were reduced from the current condition of 1280.5 kg/y to 701.6 kg/y (484.4 kg/y in surface water runoff and 217.2 kg/y in ground water). TN loadings from upstream sources were reduced from 4544.8 kg/y to 2750.2 kg/y.

Table 5.3. Estimated sources of nutrients in West Clark Lake (kg/year) Current and TMDL

	Source of Nutrient (Kgs)						
	Surface runoff		Septic tank	Ground water		Upstream inflow	
	TN	TP	TN	TN	TP	TN	TP
Current	645.7	90.5	417.6	217.2	109.7	4544.8	553
TMDL (1)	645.7	90.5	0.0	217.2	109.7	3280.9	553
TMDL (2)	484.4	68.1	0.0	217.2	109.7	2750.2	493.4

Surface runoff, septic tank, and ground water all are sources from within the West Clark Lake basin. Upstream inflow includes the sum of all loadings from surface runoff, septic tank and ground water from the upstream basins.

TMDL (1) equals removal of all septic tanks from Mirror Lake, East Clark Lake and West Clark Lake. All other conditions same as current.

TMDL (2) Final conditions to meet standards. Same as TMDL (1) with a 25 percent reduction in TN and TP from surface water runoff in both the upstream sources and from the West Clark Lake basin.

Chapter 6: DETERMINATION OF THE TMDL

6.1 Expression and Allocation of the TMDL

A TMDL can be expressed as the sum of all point source loads (wasteload allocations or WLAs), nonpoint source loads (load allocations or LAs), and an appropriate margin of safety (MOS) that takes into account any uncertainty about the relationship between effluent limitations and water quality:

As mentioned previously, the WLA is broken out into separate subcategories for wastewater discharges and stormwater discharges regulated under the NPDES Program:

$$\mathbf{TMDL} \cong \sum \mathbf{WLAs}_{\mathbf{wastewater}} + \sum \mathbf{WLAs}_{\mathbf{NPDES\ Stormwater}} + \sum \mathbf{LAs} + \mathbf{MOS}$$

It should be noted that the various components of the TMDL equation may not sum up to the value of the TMDL because a) the WLA for NPDES stormwater is typically based on the percent reduction needed for nonpoint sources and is accounted for within the LA, and b) TMDL components can be expressed in different terms [for example, the WLA for stormwater is typically expressed as a percent reduction and the WLA for wastewater is typically expressed as a mass per day].

WLAs for stormwater discharges are typically expressed as "percent reduction" because it is very difficult to quantify the loads from MS4s (given the numerous discharge points) and to distinguish loads from MS4s from other nonpoint sources (given the nature of stormwater transport). The permitting of stormwater discharges is also different than the permitting of most wastewater point sources. Because stormwater discharges cannot be centrally collected, monitored and treated, they are not subject to the same types of effluent limitations as wastewater facilities, and instead are required to meet a performance standard of providing treatment to the "maximum extent practical" through the implementation of Best Management Practices.

This approach is consistent with federal regulations [40 CFR § 130.2(I)], which state that TMDLs can be expressed in terms of mass per time (e.g. pounds per day), toxicity, or **other appropriate measure**. TMDLs for West Clark Lake are expressed in terms of pounds/year and percent reductions, and represent the maximum annual average load of TN and TP the waterbody can assimilate and maintain the Class III nutrient criterion (Table 6.1). While this TMDL is based on assuming the elimination of all septic tanks in combination with a 25 percent reduction in nutrient loadings from surface water runoff from Mirror, East Clark and West Clark Lakes, the load allocation to West Clark Lake (Table 6.1) is independent of the scenario used to obtain the reductions. For the current annual average condition, West Clark Lake receives 2,823 lbs/year (1280.5 kg/y) of TN from its basin and 10,019 lbs/year (4544.8 kg/y) of TN from upstream sources (Table 4.1). This results in a total TN loading under current conditions of 12,842 lbs/y. West Clark Lake receives 441 lbs/year (200.2 kg/y) of TP from its basin and 1,219 lbs/year (553 kg/y) of TP from upstream sources (Table 4.1). This results in a TP loading under current conditions of 1660.0 lbs/y. These estimated loadings result in annual average lake concentrations of 1.70 mg/L TN, 0.23 mg/L TP, and 44.66 ug/L chla.

For the TMDL annual average condition, West Clark Lake would receive 1548 lbs/year (702.15 kg/y) of TN from its basin (surface runoff and ground water) and 6063 lbs/year (2750.23 kg/y) of TN from all upstream sources (Table 4.1). This results in a total TN loading for the TMDL conditions of 7611 lbs/y. For the TMDL annual average condition, West Clark Lake would receive 392 lbs/year (177.88 kg/y) of TP from its basin and 1088 lbs/year (493.36 kg/y) of TP from upstream sources (Table 4.1). This results in a TP loading for the TMDL condition of 1480 lbs/y. These estimated loadings result in annual average lake concentrations of 1.018 mg/L TN, 0.217 mg/L TP, and 19.41 ug/L chl a. These concentrations result in a TSI of 59.7 (rounded 60).

Table 6.1 TMDL Allocation for Reductions in TN and TP in Surface Water Runoff

WBID	Parameter	WLA		LA (lbs/year)	MOS	TMDL (lbs/year)	* Percent Reduction
		Wastewater (lbs/year)	*Stormwater (% reduction)				
1971	TN	NA	*25%	7611	Implicit	7,610	*25
1971	TP	NA	*25%	1,480	Implicit	1,480	*25

* Percent reduction is based only on reductions from the current condition for surface water runoff from all contributing basins. The Load Allocation is from all basins and sources including ground water. Overall TN percent reduction including elimination of septic tanks in West Clark Lake, East Clark Lake, and Mirror Lake basins is 59.3. Overall reduction in TP is 10.8 percent.

6.2 Load Allocation (LA)

The allowable LA is 1480 lbs/year for TP and 7611 lbs/year for TN. This corresponds to reductions from the existing loadings of 59.3 percent for TN and 10.8 percent for TP. It should be noted that the LA may include loading from stormwater discharges regulated by the Department and the Water Management District that are not part of the NPDES Stormwater Program (see Appendix A).

6.3 WasteLoad Allocation (WLA)

NPDES Wastewater Discharges

The $WLA_{wastewater}$ is not applicable because there are no NPDES wastewater facilities present in the Lake Clark watershed.

NPDES Stormwater Discharges

The wasteload allocation for stormwater discharges is a 25% reduction in TN and TP loading from surface water runoff accompanied with elimination of all septic tanks in the contributing basins, which is the equivalent of a 59.3 percent reduction in TN and a 10.8 percent reduction in TP from all sources. It should be noted that the LA may include loading from stormwater discharges regulated by the Department and the Water

Management District that are not part of the NPDES Stormwater Program (see Appendix A).

6.4 Margin of Safety (MOS)

Consistent with the recommendations of the Allocation Technical Advisory Committee (Florida Department of Environmental Protection, February 2001), an implicit margin of safety (MOS) was used in the development of this TMDL. An implicit MOS was provided by the conservative decisions associated with a number of modeling assumptions. These include use of event mean concentrations for estimating runoff water quality, use of conservative concentrations for TN and TP as initial conditions in the model for runoff calculations.

Development of the TMDL for lakes is recommended for climatologically *average* year. However, for development of this TMDL, water quality data were available from only 2003. The main “driving force” of hydrological processes in a basin is precipitation. Therefore, we compared the annual volume of rainfall in 2003 against the long-term annual average in the region using the CIRRUS database. The two climatological stations in the City of Sarasota were closed some time ago, so we used the data from three other stations that surround the project site. One of them, in Venice (UCAN: 4169, COOP: 089176), south of Sarasota, recorded rainfall in 2003 that exceeded the 50-year (period of record) annual average by 34%. The station in Bradenton (UCAN:3873, COOP: 080945), north of Sarasota, recorded rainfall in 2003 that exceeded the 38-year (period of record) annual average by 13%. The last compared station, at Myakka River State Park (UCAN: 4062, COOP: 086065), east of Sarasota, recorded rainfall in 2003 that exceeded 50-year (period of record) annual average by 34%. Since the pollutant loads carried by surface runoff and upstream inflow are proportional to the total rainfall, and the year 2003 was considerably wetter than the average year, the estimates of the mass of nutrients that entered West Clark Lake should also exceed the mass of nutrients during an average year. Additionally, TMDL ground water contributions were held at current condition levels. These factors increase the implicit margin of safety.

Chapter 7: NEXT STEPS: IMPLEMENTATION PLAN DEVELOPMENT AND BEYOND

Following adoption of this TMDL by rule, in most cases the next step in the TMDL process is to develop an implementation plan for the TMDL, which would be a component of the Basin Management Action Plan for the Lake Clark Basin. However, if the allocation provided by this TMDL is sufficiently detailed and agreement is reached to apply the load reductions described in Chapter 6, then a BMAP would not be necessary. However, if it is determined that a BMAP is still needed, it will be developed in cooperation with local stakeholders and will attempt to reach consensus on more detailed allocations and on how load reductions will be accomplished.

The Basin Management Action Plan (B-MAP) will include:

- Appropriate allocations among the affected parties.
- A description of the load reduction activities to be undertaken.
- Timetables for project implementation and completion.
- Funding mechanisms that may be utilized.
- Any applicable signed agreements.
- Local ordinances defining actions to be taken or prohibited.
- Local water quality standards, permits, or load limitation agreements.
- Monitoring and follow-up measures.

It should be noted that TMDL development and implementation is an iterative process, and this TMDL will be re-evaluated during the BMAP development process and subsequent Watershed Management cycles. The Department acknowledges the uncertainty associated with TMDL development and allocation, particularly in estimates of nonpoint source loads and allocations for NPDES stormwater discharges, and fully expects that it may be further refined or revised over time. If any changes in the estimate of the assimilative capacity AND/OR allocation between point and nonpoint sources are required, the rule adopting this TMDL will be revised, thereby providing a point of entry for interested parties.

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APPENDICES

Appendix A. Stormwater Regulations

In 1982, Florida became the first state in the country to implement statewide regulations to address the issue of nonpoint source pollution by requiring new development and redevelopment to treat stormwater before it is discharged. The Stormwater Rule, as authorized in Chapter 403, Florida Statutes (F.S.), was established as a technology-based program that relies upon the implementation of BMPs that are designed to achieve a specific level of treatment (i.e., performance standards) as set forth in Chapter 62-40, Florida Administrative Code (F.A.C.).

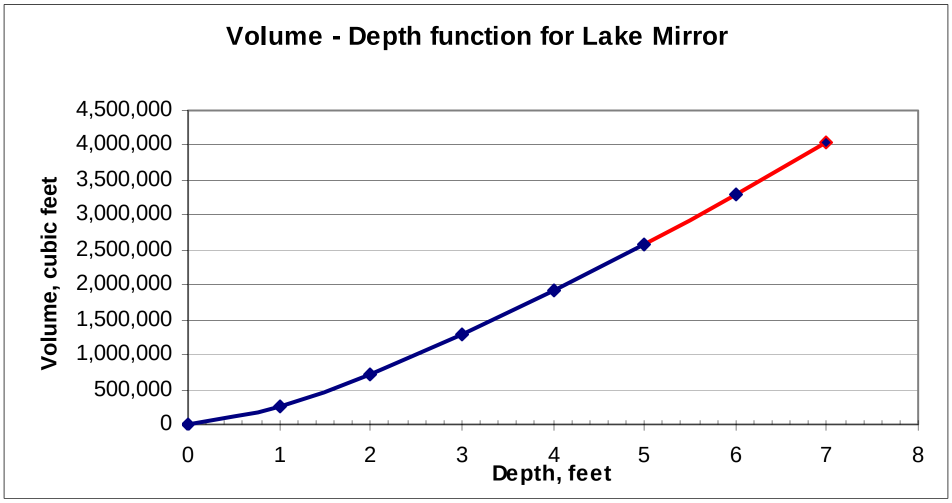
The rule requires Water Management Districts (WMDs) to establish stormwater pollutant load reduction goals (PLRGs) and adopt them as part of a SWIM plan, other watershed plan, or rule. Stormwater PLRGs are a major component of the load allocation part of a TMDL. To date, stormwater PLRGs have been established for Tampa Bay, Lake Thonotosassa, Winter Haven Chain of Lakes, the Everglades, Lake Okeechobee, and Lake Apopka. No PLRG has been developed for Trout Lake at the time this study was conducted.

In 1987, the U.S. Congress established section 402(p) as part of the Federal Clean Water Act Reauthorization. This section of the law amended the scope of the federal NPDES to designate certain stormwater discharges as “point sources” of pollution. These stormwater discharges include certain discharges that are associated with industrial activities designated by specific Standard Industrial Classification (SIC) codes, construction sites disturbing five or more acres of land, and master drainage systems of local governments with a population above 100,000 [which are better known as “municipal separate storm sewer systems” (MS4s)]. However, because the master drainage systems of most local governments in Florida are interconnected, EPA has implemented Phase 1 of the MS4 permitting program on a county-wide basis, which brings in all cities (incorporated areas), Chapter 298 urban water control districts, and the DOT (Department of Transportation) throughout the 15 counties meeting the population criteria.

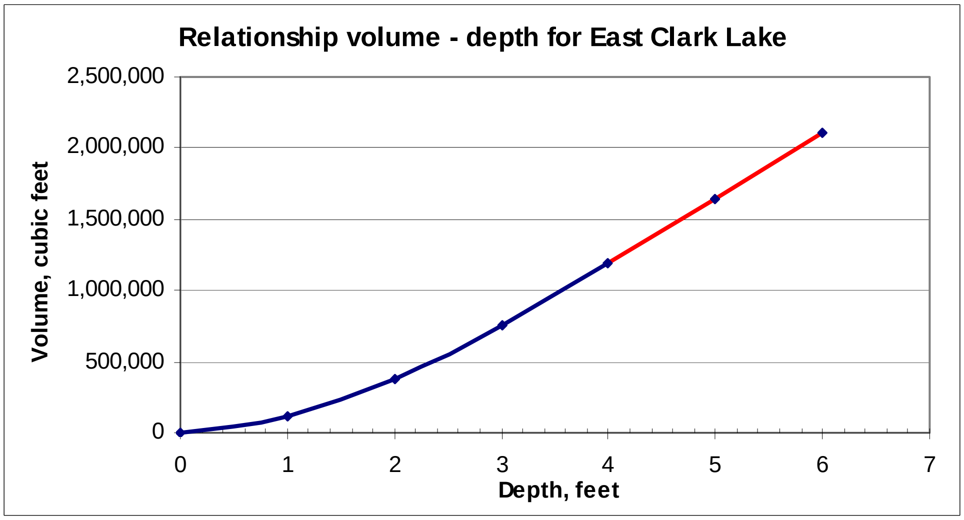
An important difference between the federal and the state stormwater permitting programs is that the federal program covers both new and existing discharges while the state program focuses on new discharges. Additionally, Phase 2 of the NPDES stormwater permitting program will expand the need for these permits to construction sites between one and five acres, and to local governments with as few as 10,000 people. These revised rules require that these additional activities obtain permits by 2003. While these urban stormwater discharges are now technically referred to as "point sources" for the purpose of regulation, they are still diffuse sources of pollution that can not be easily collected and treated by a central treatment facility similar to other point sources of pollution, such as domestic and industrial wastewater discharges. The DEP recently accepted delegation from EPA for the stormwater part of the NPDES program. It should be noted that most MS4 permits issued in Florida include a re-opener clause that allows permit revisions to implement TMDLs once they are formally adopted by rule.

Appendix B. Bathymetry maps and detention volume – depth functions

On 11/09/2004 Lake's Mirror depth was rounded to five feet which corresponded to stage 8.86 ft. For another stage, for example 9.46 ft, volume of water detained in Lake Mirror corresponds to depth 5.60 ft and is estimated as 3,000,000 cubic feet.

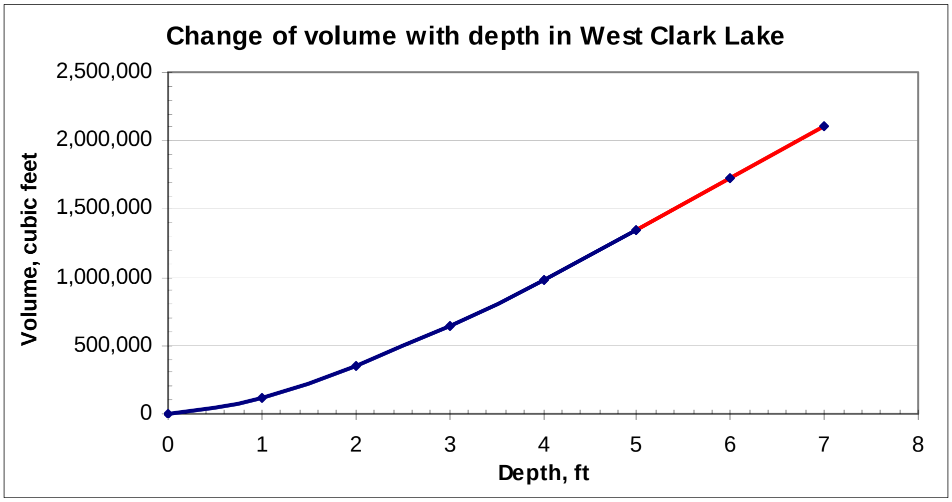


On 11/09/2004 East Clark Lake's depth was rounded to four feet, which corresponded to

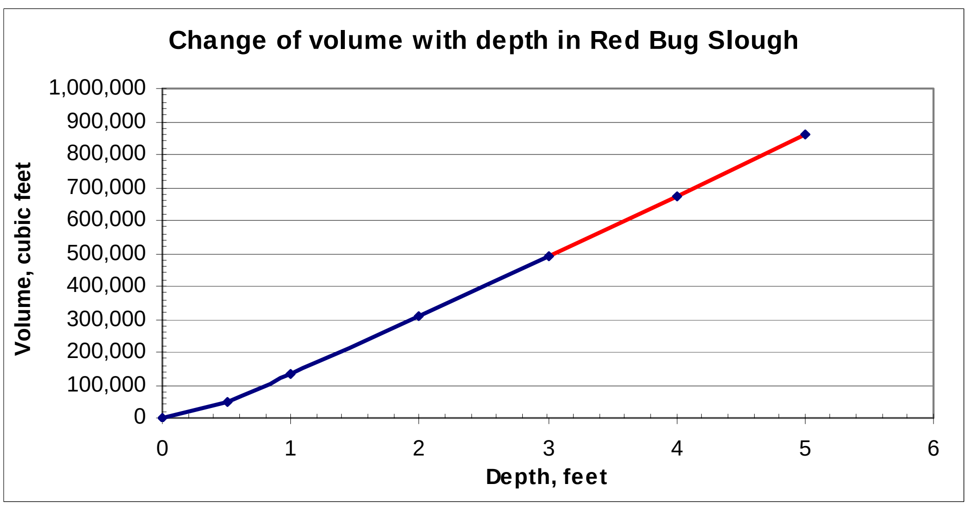


water stage 4.85 ft.

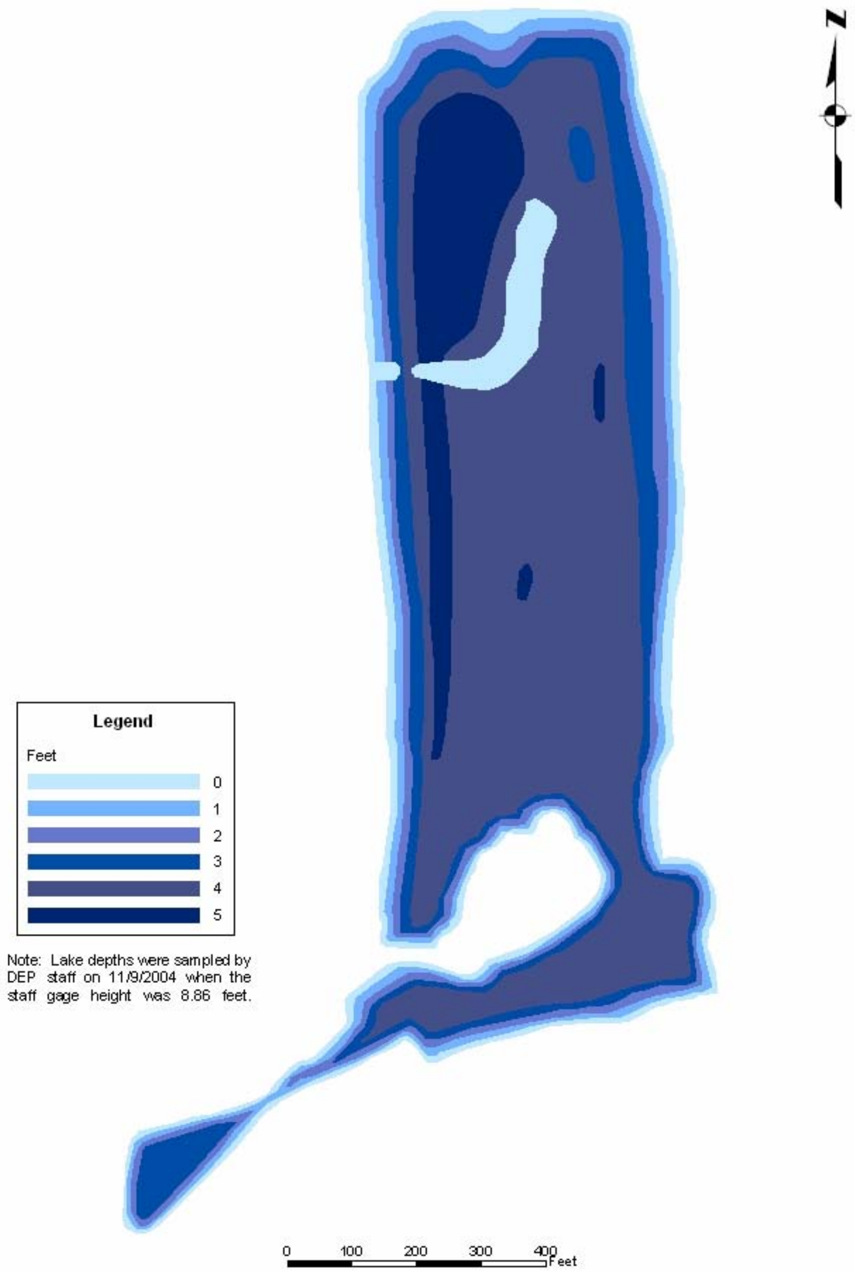
On 11/9/2004 West Clark Lake's depth was rounded to five feet, which corresponded to water stage 8.73 ft.



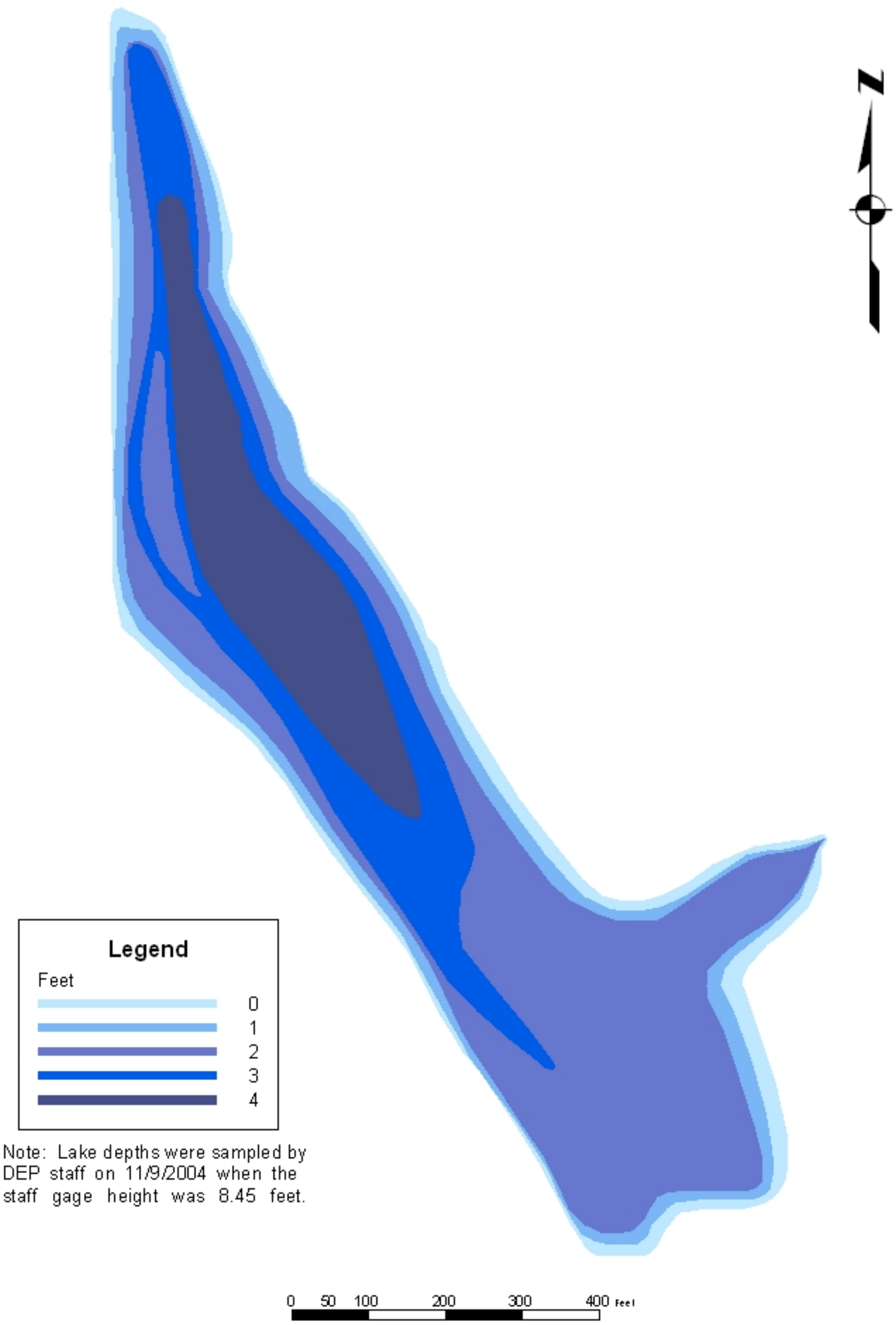
On 11/9/2004 Red Bug Slough's depth was rounded to three feet, which corresponded to water stage 8.42 ft.



MIRROR LAKE BATHYMETRY

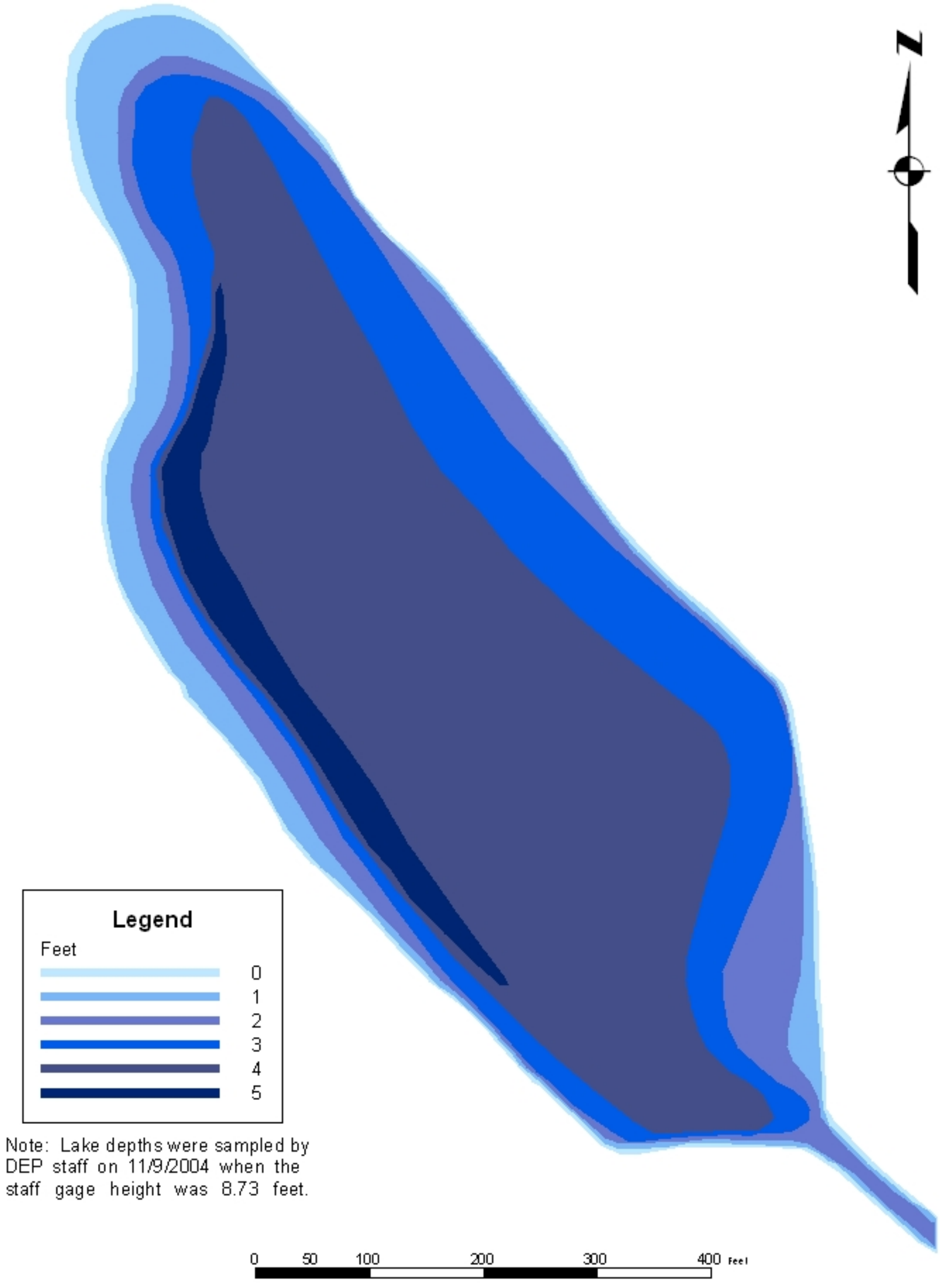


EAST CLARK LAKE BATHYMETRY



Note: Lake depths were sampled by DEP staff on 11/9/2004 when the staff gage height was 8.45 feet.

WEST CLARK LAKE BATHYMETRY



RED BUG LAKE BATHYMETRY

Appendix C. Monthly tables of water budget in Lake Clark. These tables served for prediction of ground water inflow to Lake Clark in each month

January 2003

Precipitation (inches):	0						
Evaporation (inches):	2.7						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	161,502	0	0	128,062	579,080	2,750,000	265,640
East Lake Clark:	421,216	579,080	0	81,494	2,869,478	1,130,000	1,780,676
West Lake Clark:	131,636	2,869,478	0	67,417	3,729,410	1,345,000	685,713

February 2003

Precipitation (inches):	0						
Evaporation (inches):	3.3						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	143,266	0	0	155,097	392,001	2,700,000	353,832
East Lake Clark:	226,693	392,001	0	98,698	1,554,503	1,113,000	1,017,507
West Lake Clark:	83,056	1,554,503	0	81,650	1,931,704	1,352,000	382,795

March 2003

Precipitation (inches):	0						
Evaporation (inches):	4.5						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	311,241	0	0	212,488	673,801	2,690,000	565,048
East Lake Clark:	675,645	673,801	0	135,219	2,726,528	1,080,000	1,479,301
West Lake Clark:	222,355	2,726,528	0	111,863	3,396,586	1,350,370	557,936

				April 2003				
Precipitation (inches):		0						
Evaporation (inches):		5.56						
		Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:		395,811	0	0	263,713	816,719	2,725,000	719,621
East Lake Clark:		996,994	816,719	0	167,817	3,405,853	1,100,000	1,779,957
West Lake Clark:		318,174	3,405,853	0	138,830	4,234,235	1,385,000	683,668
				May 2003				
Precipitation (inches):		0						
Evaporation (inches):		6.3						
		Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:		647,186	0	0	298,337	1,602,767	2,720,000	1,248,918
East Lake Clark:		1,733,778	1,602,767	0	189,850	6,951,151	1,075,000	3,779,456
West Lake Clark:		548,784	6,951,151	0	157,058	8,659,498	1,364,000	1,295,621
				June 2003				
Precipitation (inches):		0						
Evaporation (inches):		5.9						
		Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:		5,647,031	0	0	278,416	7,556,682	4,650,000	4,118,067
East Lake Clark:		19,043,900	7,556,682	0	177,173	33,764,215	1,340,000	7,605,806
West Lake Clark:		5,997,865	33,764,215	0	146,570	41,989,802	1,565,000	2,575,292

July 2003

Precipitation (inches):	0						
Evaporation (inches):	5.68						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	624,186	0	0	269,404	1,361,771	3,168,000	-475,011
East Lake Clark:	1,370,802	1,361,771	0	171,439	5,585,188	1,145,000	2,829,054
West Lake Clark:	444,565	5,585,188	0	141,826	7,015,716	1,390,000	952,789

August 2003

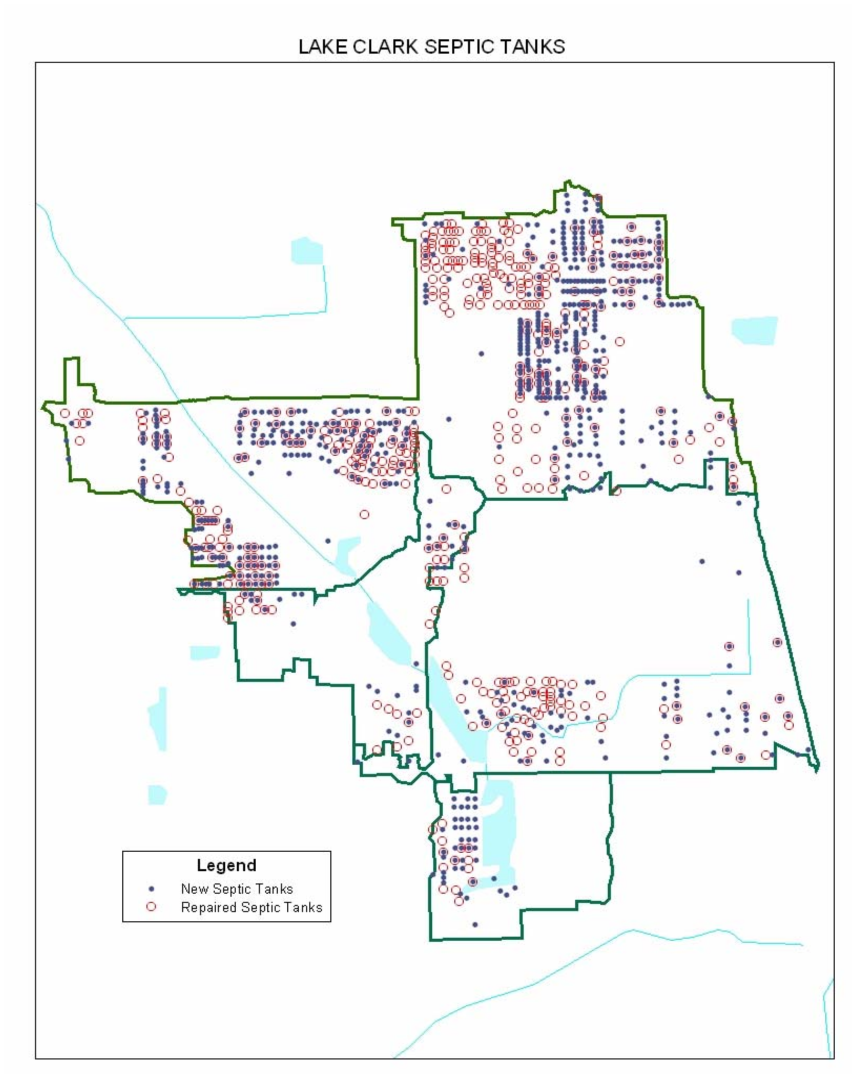
Precipitation (inches):	0						
Evaporation (inches):	5.3						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	1,447,000	0	0	252,329	2,425,180	3,030,000	1,092,509
East Lake Clark:	3,708,234	2,425,180	0	160,573	9,589,428	1,260,000	3,731,587
West Lake Clark:	1,169,843	9,589,428	0	132,837	11,756,925	1,455,000	1,195,491

September 2003

Precipitation (inches):	0						
Evaporation (inches):	4.8						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	1,377,110	0	0	227,666	2,298,580	3,060,000	1,179,136
East Lake Clark:	4,004,974	2,298,580	0	144,878	10,020,805	1,255,000	3,857,129
West Lake Clark:	1,259,604	10,020,805	0	119,853	12,565,889	1,440,000	1,390,333

				October 2003				
Precipitation (inches):		0						
Evaporation (inches):		4.32						
		Lateral inflow	Inflow from	Direct	Evaporation	Discharge	Water in the	Ground water
			upstream lake	rainfall			Lake at the	inflow
							end of month	
Lake Mirror:		182,151	0	0	204,899	605,508	2,725,000	293,256
East Lake Clark:		319,742	605,508	0	130,390	2,541,632	1,175,000	1,666,772
West Lake Clark:		111,517	2,541,632	0	107,868	3,189,236	1,360,000	563,955
				November 2003				
Precipitation (inches):		0						
Evaporation (inches):		3.2						
		Lateral inflow	Inflow from	Direct	Evaporation	Discharge	Water in the	Ground water
			upstream lake	rainfall			Lake at the	inflow
							end of month	
Lake Mirror:		219,226	0	0	150,828	751,582	2,665,000	623,184
East Lake Clark:		474,603	751,582	0	95,982	3,240,202	1,165,000	2,099,999
West Lake Clark:		155,797	3,240,202	0	79,403	4,042,605	1,350,370	716,379
				December 2003				
Precipitation (inches):		0						
Evaporation (inches):		2.6						
		Lateral inflow	Inflow from	Direct	Evaporation	Discharge	Water in the	Ground water
			upstream lake	rainfall			Lake at the	inflow
							end of month	
Lake Mirror:		658,873	0	0	123,793	1,532,767	2,825,000	1,157,687
East Lake Clark:		1,892,863	1,532,767	0	78,777	6,731,181	1,155,000	3,374,328
West Lake Clark:		591,245	6,731,181	0	65,170	8,382,825	1,350,370	1,125,569

Appendix D. Septic Tank Locations.



Appendix F. Monthly tables of water budget in Lake Clark. These tables served for prediction of ground water inflow to Lake Clark in pre-development scenario.

			January 2003				
Precipitation (inches):	0						
Evaporation (inches):	2.7						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	102,885	0	0	128,064	344,001	2,725,000	109,179
East Lake Clark:	218,616	344,001	0	81,497	1,634,566	1,129,200	1,044,647
West Lake Clark:	76,315	1,634,566	0	67,415	2,126,513	1,345,000	414,047
			February 2003				
Precipitation (inches):	0						
Evaporation (inches):	3.27						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	112,764	0	0	155,099	257,782	2,680,000	255,118
East Lake Clark:	121,085	257,782	0	98,702	924,350	1,106,000	620,985
West Lake Clark:	57,322	924,350	0	81,647	1,152,656	1,348,800	256,431
			March 2003				
Precipitation (inches):	0						
Evaporation (inches):	4.48						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	215,879	0	0	212,491	427,718	2,649,000	393,330
East Lake Clark:	346,450	427,718	0	135,225	1,579,466	1,078,800	913,324
West Lake Clark:	134,682	1,579,466	0	111,859	1,976,260	1,348,800	373,972

	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
			April 2003				
Precipitation (inches):	0						
Evaporation (inches):	5.56						
Lake Mirror:	266,306	0	0	263,717	513,458	2,641,500	503,369
East Lake Clark:	551,723	513,458	0	167,824	2,000,439	1,083,000	1,107,282
West Lake Clark:	195,964	2,000,439	0	138,825	2,496,065	1,367,800	457,487

	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
			May 2003				
Precipitation (inches):	0						
Evaporation (inches):	6.29						
Lake Mirror:	438,999	0	0	298,341	1,007,292	2,619,000	844,134
East Lake Clark:	1,013,909	1,007,292	0	189,858	4,171,205	1,069,300	2,326,163
West Lake Clark:	350,094	4,171,205	0	157,052	5,210,646	1,356,400	834,999

	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
			June 2003				
Precipitation (inches):	0						
Evaporation (inches):	5.87						
Lake Mirror:	4,348,202	0	0	278,420	5,879,107	4,111,000	3,301,325
East Lake Clark:	14,472,079	5,879,107	0	177,181	26,108,372	1,247,600	6,112,667
West Lake Clark:	4,651,614	26,108,372	0	146,566	32,565,737	1,491,300	2,087,217

			July 2003				
Precipitation (inches):	0						
Evaporation (inches):	5.68						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	425,121	0	0	269,408	1,066,732	2,953,000	-246,981
East Lake Clark:	681,197	1,066,732	0	171,446	4,211,705	1,124,500	2,512,122
West Lake Clark:	264,038	4,211,705	0	141,822	5,307,030	1,375,500	857,309
			August 2003				
Precipitation (inches):	0						
Evaporation (inches):	5.32						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	955,348	0	0	252,333	1,812,431	2,816,000	972,416
East Lake Clark:	2,005,838	1,812,431	0	160,580	6,926,986	1,195,000	3,339,797
West Lake Clark:	707,785	6,926,986	0	132,833	8,569,785	1,410,000	1,102,347
			September 2003				
Precipitation (inches):	0						
Evaporation (inches):	4.8						
	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	950,119	0	0	227,669	1,824,492	2,847,000	1,133,042
East Lake Clark:	2,529,232	1,824,492	0	144,884	7,789,762	1,204,500	3,590,422
West Lake Clark:	843,870	7,789,762	0	119,849	9,788,468	1,402,300	1,266,985

October 2003

Precipitation (inches):	0					
Evaporation (inches):	4.32					

	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	135,302	0	0	204,902	470,687	2,649,000	342,287
East Lake Clark:	157,479	470,687	0	130,396	1,904,427	1,171,400	1,373,557
West Lake Clark:	70,794	1,904,427	0	107,864	2,393,299	1,356,400	480,042

November 2003

Precipitation (inches):	0					
Evaporation (inches):	3.18					

	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	151,163	0	0	150,831	460,752	2,626,000	437,420
East Lake Clark:	241,278	460,752	0	95,986	1,873,579	1,162,200	1,258,334
West Lake Clark:	93,756	1,873,579	0	79,400	2,343,397	1,345,000	444,062

December 2003

Precipitation (inches):	0					
Evaporation (inches):	2.61					

	Lateral inflow	Inflow from upstream lake	Direct rainfall	Evaporation	Discharge Total	Water in the Lake at the end of month	Ground water inflow
Lake Mirror:	437,373	0	0	123,795	974,374	2,748,000	782,796
East Lake Clark:	1,131,244	974,374	0	78,781	4,137,247	1,152,700	2,100,910
West Lake Clark:	377,307	4,137,247	0	65,168	5,166,127	1,348,700	720,441

Appendix G. Websites that provide an estimate of waterfowl weight by bird species

Cormorant: http://www.saltgrassflats.com/birds/cormorant_dblcrested.html

Anhinga: http://animaldiversity.ummz.umich.edu/site/accounts/information/Anhinga_anhinga.html

White Ibis: http://www.audubon.org/bird/BoA/F37_G1c.html

Glossy Ibis: http://nationalzoo.si.edu/Animals/Birds/Index/default.cfm?id=160

Common Egret: http://dep.state.ct.us/burnatr/wildlife/factshts/gegret.htm

Snowy Egret: http://dep.state.ct.us/burnatr/wildlife/factshts/snegret.htm

Black-crowned Night Heron: http://www.hoglezoo.org/animals/view.php?id=110

Little Blue Heron: http://www.saltgrassflats.com/birds/little_blue_heron.html

Louisiana Heron: http://fwie.fw.vt.edu/TN/TN11126h.htm

Tri-colored Heron: http://www.saltgrassflats.com/birds/tricolor_heron.html